SHAFT-SINKING

UNDER DIFFICULT CONDITIONS

BY

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TRANSLATED FROM THE GERMAN

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Eighteen Engravings in the Text and Nineteen Plates

FIRST EDITION

FIRST THOUSAND

NEW YORK

JOHN WILEY & SONS

LONDON: CHAPMAN & HALL, LIMITED

1907

ROBERT DRUMMOND COMPANY, PRINTERS, NEW YORK

TRANSLATORS' PREFACE.

It is believed that the translation of this work into English, undertaken with the Author's approval, will prove to be of some value to mining engineers and students of mining. The subjects dealt with have been hitherto rather outside of the field of practice of American engineers, perhaps chiefly because there has been but little need thus far in this country for attempting the development of such mineral deposits as are overlaid by deep accumulations of unstable, water-bearing soils, or alternations of these with rocky strata.

Our mineral deposits are generally accessible by shafts sunk under more favorable conditions. Considerable areas of the continental coal measures, as well as some of the important deposits of salt, gypsum, etc., are covered by geological formations of which no exact parallel has yet been encountered in this country. It would, for example, be difficult to duplicate here at present such adverse conditions as are set forth in the geological sections described in the tables on pages 90 and 137, in point both of depth and of the extremely unfavorable nature of the soft, water-bearing strata overlying the mineral deposits.

However, the time cannot be far distant when our own less easily worked mineral deposits must receive attention, making necessary the sinking of shafts more or less under the conditions described in the following pages. Some shafts

have already been put down in difficult, water-bearing formations, in the iron regions of northern Michigan, in the anthracite fields of Pennsylvania, in southern Louisiana for sulphur and salt, and elsewhere. Possibly the difficulties, or the partial or complete failure, of some of these enterprises might have been avoided if their projectors had had knowledge of the successes achieved in similar circumstances by European engineers.

Comparatively little of the literature of this interesting field of engineering has appeared in the English language, and we venture to hope that the translation of this brief monograph will meet with a favorable reception among mining engineers. It may not be amiss to point out that some of the methods of sinking herein described—or at least adaptations of them—are applicable also for the moderate depths usually reached by civil engineers, in building deep foundations in watery soils for heavy structures.

C. R. CORNING.
ROBERT PEELE.

NEW YORK, May, 1907.

AUTHOR'S PREFACE.

THE present work consists chiefly of a revision and amplification of previous publications, dealing with shaft-sinking, issued by the firm of Haniel & Lueg of Düsseldorf, Privy Counselor H. Lueg, Bergrath Lücke, General Manager B. Schulz-Briesen, and the present writer. These articles and books comprise:

1. "Shaft-sinking at the Time of the Düsseldorf Exhibition of 1902", by the present author.

2. "Recent Progress in Shaft-sinking"; a paper read by the present author before the Eighth German Mining Convention at Dortmund, 1901.

3. "Modern Methods of Shaft-sinking", by Haniel & Lueg, 1896.

4. "Recent Developments in Methods of Shaft-sinking through Quicksand", 1896; a paper read by the author before the Lower Rhine Branch of the Society of German Engineers.

5. "Shaft-sinking through Quicksands in Shaft No. III of the Rheinpreussen Mine, near Homberg on the Rhine", 1896, by Bergrath Lücke.

6. "Innovations in Shaft-sinking through Lignite Formations", 1893, by Privy Counselor Lueg.

7. "Shaft-boring by the Kind-Chaudron System", 1884, by General Manager Schulz-Briesen.

Most of these articles appealed only to the small number of professional engineers who make a specialty of shaft-sinking, and were therefore very brief. The following pages are intended for a wider circle of mining engineers, as well as for students of this branch of engineering, though the presentation of the subject is not so general in character as to lack interest for the specialist. This fuller treatment is thought to be justified by the courteous reception accorded to the previous articles, especially that of 1902, by the engineering profession both at home and abroad.

Much of the matter contained in the previous publications has already become obsolete and is omitted, to avoid rendering the book cumbersome and also to make room for detailed descriptions of the more modern methods now requiring discussion.

As indicated by the title, the only methods explained at length are those which deal with shaft-sinking under difficult conditions. Those modern methods which depend almost exclusively on hand labor are described first, chiefly for the purpose of furnishing a basis of comparison by which to measure recent progress in other directions. The author's principal aim has been to present a brief review of methods actually in use, in order to aid mine managers and others in authority in their choice of what would be suitable under given conditions. It is hoped that this mode of presenting the subject may prove to be acceptable. While the number of individual examples has been reduced, there are still enough to illustrate and explain all details of the various methods. Speaking in a general way, it has been deemed best in the individual cases to describe fully each example of shaft-sinking discussed, rather than to restrict mention thereof to the particular method of

work which may ultimately have led to final success. In endeavoring throughout to maintain an impartial attitude, the author has found it necessary to go into rather full descriptive details of each piece of work, so as to afford the reader ample opportunity to form his own judgment.

The author desires to express here his sincere appreciation of the courteous responses which have been invariably accorded to his requests for information.

THE AUTHOR.

DÜSSELDORF, 1905.

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UNDER DIFFICULT CONDITIONS.

I.

SHAFT-SINKING BY HAND.

None of the modern methods of shaft-sinking under difficult conditions, in fact no mechanical process of sinking, has as yet successfully displaced sinking by hand, which, when at all applicable, still maintains its predominance over other methods. The great majority of shafts are to-day put down by hand labor, with the use of modern high explosives, the drainage being effected by means either of buckets, of Cornish, steam, or compressed-air sinking-pumps, or of the Tomson water-hoist.

The activity in shaft-sinking during the past few years has brought about many improvements, such as the use of hanging scaffolds, by means of which the masonry lining, or the tubbing, may be put in place simultaneously with the actual sinking operations. Progress has also been made in pumping the water, the old Cornish pumps having been improved and so arranged that they are suspended in the shaft by ropes and can be readily raised or lowered. Steam sinking-pumps, similarly supported, are now much in vogue, though they are always sources of considerable heat in the shaft. Com-

pressed air is therefore gradually replacing steam as a motive power for these pumps.

Tomson's method of bailing by means of the permanent hoisting-engine is much less open to the above objections. It is true that Pulsometer pumps, which are frequently employed to raise water from the bottom to shaft-tanks above, increase the temperature only slightly, but their efficiency is low and they are of late being advantageously replaced by compressed-air pumps. Tomson's water-hoisting apparatus, operated by the regular hoisting-engine, has none of the drawbacks of the pumps and is consequently becoming more and more popular, particularly for very wet shafts. One of the best examples of its use was to be seen during the sinking of the Wintershall Company's shaft, at Heringen, in Thuringia. A description of this work, from which we cite the following data, was given in "Industrie" (Berlin) No. 48, 1902. The water-bearing bed of dolomite lies at a depth of 228 to 255 m. (748 to 836 ft.) below the collar of the shaft, and is 27 m. (88.5 ft.) thick. Such a depth is too great for lift-pumps and the management hesitated to put in plunger-pumps, as it was thought best to be ready at any moment to remove everything from the shaft preparatory to using boring apparatus. The Tomson water-hoisting plant eventually installed is the largest yet used. Three hoists were put in: one with a cylinder 942 mm. (36.7 ins.) diameter by 1884 mm. (73.5 in.) stroke; the second, 942 mm. by 1570 mm. (36.7×61.25 in.); and the third, 890 mm. by 1570 mm. (34.7×61.25 in.). The first two were designed to raise water-buckets of 10 cbm. (2642 galls.) capacity from a depth of 300 m. (984 ft.), and the smaller one for 6-cbm. (1584 galls.) buckets from the same depth.

This plant could easily hoist 15 to 16 cbm. (4226 galls.) of

water per trip from a depth of 300 m. (984 ft.). The apparatus was suspended by ropes in the shaft, and the two accompanying receiving water-tanks had each a capacity of 36 cbm. (9504 galls.). The water was pumped from the sump into these tanks by duplex pumps, operated by compressed air and bolted to the tanks themselves. Each of these, when full of water, weighed 70,000 kg. (154,000 lbs.). The dolomite proved to be much firmer and more compact at Wintershall than in the other shafts put down in Thuringia, so that the total flow of water did not exceed 6 cbm. (1584 galls.) per minute and it was never necessary to run the equipment at its full capacity. The dolomite was reached December 1, 1901, and the shaft passed out of the same February 12, 1902, at a depth of 258 m. (846 ft.). At this point operations for shutting off the water were commenced, which indicated that the work had been successful.

All three of the above methods of unwatering a shaft may be so arranged that, if necessary, the shaft can be drained even if the apparatus be under water at the commencement of operations. Stationary pumps are now no longer customary for shaft-sinking.

The improvements referred to, together with careful planning and efficient organization of the work, have brought about phenomenal results in sinking by hand, providing the flow of water be not too large. A few examples may be cited:

At Aschersleben, Shaft V was sunk 286.4 m. (939 ft.) in 252 days, including the installation of the lining and hoisting guides. From a point 18.6 m. (61 ft.) below the collar to 216 m. (708 ft.), that is, a depth of 197.4 m. (847 ft.), the shaft was sunk, lined with tubbing and completed ready for hoisting, in 176 days. The average progress for the total depth,

286 m. (938 ft.) of completed shaft, was 1.12 m. (3.67 ft.) per day; and the total cost, including tubbing, bolts, lead, concrete, wages, and general expenses, was 1750 marks per meter ($134 per ft.). We may add that a type of stuffing-box (Pat. No. 65012) used in connection with the shaft-lining in order to avoid the necessity of calking the joints, worked well during the past winters. They have not leaked, although movement in them has taken place on account of changes of temperature; and this in spite of the fact that at the same time much trouble was experienced in Westphalia because of leaky shaft-linings.

At the first of the two Georgs-Marien-Hütte shafts, near Werne, Westphalia, marl was encountered at 25 m. (82 ft.) below the collar and continued to a depth of 459 m. (1505 ft.), i.e., a distance of 434 m. (1423 ft.), which was sunk in 9 months, or a rate of 48.2 m. (158 ft.) per month. The total time required for sinking to the coal-beds at a depth of 580 m. (1902 ft.), including 10.6 m. (35 ft.) of quicksand at the surface and the lining of that portion with tubbing, was 20 months (from September 1, 1899, to May 2, 1901). Average progress was 29 m. (95 ft.) per month; maximum progress in one month, 60 m. (197 ft.) There was comparatively little water, although two rather considerable flows were encountered: one at 460 m. (1509 ft.) of 150 liters (40 galls.) per minute, and another at 555 m. (1820 ft.) on the bedding-plane between two sandstone strata, of 90 l. (24 galls.) per minute, which somewhat retarded sinking below these points. Similar conditions prevailed in the second shaft.

The Wilhelmshall shaft, at Oelsburg, affords another fair sample of this character of work. Actual sinking commenced June 1, 1900, with a drop-shaft 6.8 m. (22.3 ft.) in the clear. At a depth of 6.4 m. (21 ft.) argillaceous gypsum was found,

and on June 24, at 17 m. (56 ft.), the drop-shaft stuck fast in gypsum gravel. A short delay then occurred because of necessary boiler repairs. The flow of water, 1 cbm. (264 galls.) per minute, was raised by means of Diaphragm pumps. The gypsum gravel overlay beds of clays, which were passed through without encountering any material flow of water.

After reaching a total depth of 48 m. (157 ft.) and lining the shaft with temporary timbering, supported by channel-iron rings, a wedging-crib was put in place and the permanent lining of cast-iron tubbing, 5.5 m. (18 ft.) in diameter, with planed joints, was built up into the original drop-shaft. The tubbing held back the surface-water and sinking was thenceforth pushed more rapidly.

The ground next encountered consisted of red and blue clay, with bands of gypsum and anhydrite. Ordinary brick walling, with a thickness of two bricks, was adopted for lining. Between 82 m. (269 ft.) and 104 m. (341 ft.), the shaft passed through gypsum and anhydrite, giving place farther down to alternating layers of blue and red clay. At a depth of 200 m. (656 ft.) the formation changed to a gray saliferous clay, followed at 203 m. (666 ft.) by the bed of rock-salt. The shaft-lining was built in separate sections, each 40 m. (131 ft.) high and with independent footings. This masonry work was done from a suspended platform while the sinking was in progress.

The shaft was enlarged below the tubbing so that the lining was 6 m. (19.7 ft.) in the clear. The formation down to the saliferous clay was fairly flat, whereas the clay stratum itself dipped from 70° to 90° and followed the shaft for some 30 m. (98 ft.), so that the latter stood in clay on one side and rock-salt on the other. At 235 m. (771 ft.) the dip of the clay flat-

tened, and sinking was continued in the rock-salt, the lining being built in sections. On August 21, 1901, after reaching a depth of 520 m. (1706 ft.), salt water broke so strongly through the lining into the shaft at about 203 m. (666 ft.), the horizon of the salt clay, that the work was drowned out. An attempt to pump out the water proved futile. Until this mishap occurred the entire work, including sinking, tubbing, and masonry lining, to a depth of 520 m. (1706 ft.), had occupied 423 days, corresponding to an average advance of 1.23 m. (4 ft.) per calendar day, or about 1.5 m. (4.9 ft.) per working day.

When shafts are sunk by hand, tubbing with machined joints and lead packing and bolted together on the inside, is invariably used where masonry proves insufficient. Lining of this character is absolutely water-tight. So-called English tubbing, with outside rough flanges and wooden wedging but without bolts or packing, is almost entirely obsolete. It is heavier, more expensive per running meter of shaft, slower to erect, and less reliable than machined tubbing.

Some time since the author had occasion to note the importance of the advance made fifty years ago by the introduction into Westphalia of English tubbing, and the sinking of round shafts. It was when visiting the air-shaft at the Zollern No. 1 mine. This shaft was started by the English, put down 5.35 m. (17.5 ft.) in the clear to a depth of 66 m. (216 ft.), and lined with English tubbing. Because of the excessive inflow of water it was abandoned. It is reported that 40 cbm. (10,560 galls.) of water were raised per minute. For forty years the shaft was flooded, and when unwatered the iron lining was found in perfect condition, as it was built in the best manner, both as to material and execution of the work. From the standpoint of the mechanical engineer, it was most interesting

to find the four heavy and antiquated lift-pumps which had been abandoned in the shaft. Their massive wooden rods, having been under water so long, were still in very good condition. Plate I shows this interesting shaft, together with the pumps.

An innovation which has recently become popular, and which was first adopted on a large scale on the ship-elevator, built by Haniel & Lueg, near Henrichenburg, is the installation of suspended tubbing underneath a wedging-crib, instead of building the tubbing on top of such a crib. This method saves all expensive temporary timbering, as well as the loss of time and money incidental thereto. It secures the further advantage that the shaft is at all times fully and permanently lined down to a point not over 1½ m. (4.9 ft.) above the bottom, thus preventing any danger of loose material falling from the sides. This plan was adopted at Shaft II of "Zeche Zollern No. 2", though there was but a small flow of water, and the results were so satisfactory that the subsequent sinking of the air-shaft at "Zeche Zollern No. 1", mentioned above, was carried out in the same way.

Suspended tubbing was used below the drop-shafts at the Deutscher Kaiser shafts I, II, and III, as well as at Rheinpreussen I and Hugo I shafts. The latter shaft was sunk in dry sand. At Sterkrade No. I the water below the drop-shaft was also shut off by suspended tubbing.

The continuation of the sinking of the air-shaft at Zollern No. 1 was interesting in that large amounts of water were certain to be met with. On account of the good results obtained at shaft II of Zollern No. 2, Bergassessor Randebrock, manager of the mine, decided, in spite of adverse criticism, to adopt suspended tubbing. The successful completion of the

shaft amply justified his decision. The following notes of this work, which comprise many items of interest, are mainly the memoranda of Manager Apprecht of Zollern No. 2. As stated above and shown also on Plate I, this shaft had been sunk to a depth of 66 m. (216 ft.), lined with English tubbing, and finally abandoned by the English company because of an unmanageable inflow of water.

The unwatering of the shaft was begun with a steam sinking-pump, throwing 6 cbm. (1584 galls.) per minute. The inflow at the bottom was found to be only 3 cbm. (792 galls.) per minute. After sinking 4 m. (13 ft.) a wedging-crib was put in, machined on the lower as well as upper side, and provided with bolt-holes. Two rings of German machined tubbing, each 1.5 m. (4.9 ft.) high, were then set above this crib and joined to the old English tubbing by means of a closing-ring. As sinking proceeded the water increased until, at a depth of 69 m. (226 ft.), it amounted to 6.5 cbm. (1716 galls.) per minute, and at 71 m. (233 ft.) a maximum of 7 cbm. (1848 galls.) per minute. From this point downward the flow decreased. At 72 m. (236 ft.) 5.5 cbm. (1452 galls.) per minute were raised, at 77 m. (253 ft.), only 0.35 cbm. (93 galls.). The flow increased at 83 m. (272 ft.) to 0.5 cbm. (132 galls.), while at 93 m. (305 ft.) the shaft was practically dry.

Plate II shows the completed shaft, as well as the details enumerated in the description below. The sections of the suspended tubbing were each 1.5 m. (4.9 ft.) high and differed from the ordinary machined tubbing in having several horizontal outside ribs, projecting some 10 mm. (0.39 in.) and intended to aid in gripping the concrete backing. Furthermore, in each segment immediately above the bottom horizontal flange there was an inclined hole, 65 mm. (2.5

ins.) in diameter, through which concrete backing was introduced.

Sinking proceeded by excavating 1.5 m. (4.9 ft.) of the shaft at a time, and immediately putting a ring in place. The rings were erected by first lowering the segments to the bottom of the shaft near their final position; then they were picked up by the tongs shown in Plate II and held underneath the flange thereby making a temporary connection. After removing the tongs and placing the lead packing in position, the segment was made fast to the rings above by screwing up the bolts. After placing all of the ten segments in a similar manner, the vertical joints were filled with lead packing and all bolts tightened up.

The walls of the shaft were smoothed off with particular care just below the bottom of each ring, so that a fairly tight joint could be made by means of the bent plates as shown in Plate II, which were bolted on below the bottom flange. In order to secure a still better fit these metal plates were supplied with slotted bolt-holes, as shown. Any openings remaining after putting on these plates were plugged with wooden wedges. Then the space between the tubbing and the wall of the shaft was filled with concrete through the 65-mm. (2.5-in.) holes already mentioned, with the help of the funnel shown in Plate II. At the same time, any flow of water was tapped through similar 65-mm. holes in some of the upper rings. The concrete consisted as a rule of one part of cement to four parts of sand; though at the bottom the proportion was altered to one part cement for each two of sand. The concrete set in forty-eight hours, during which time the next 1.5 m. (4.9 ft.) of shaft was sunk. When fissures with flowing water were encountered they were carefully enlarged, cleaned out, and then closed by placing a

board in front of them to direct their flow of water off under the lowest tubbing and so secure still water behind the permanent shaft-lining when concreting. (See Plate II.) The setting of a tubbing-ring usually occupied about six hours, the packing and concreting rarely more than twelve hours.

Bergassessor Randebrock writes me that the methods adopted by Haniel & Lueg for the shafts of the ship-elevator, already referred to, induced him to apply suspended tubbing in sinking shafts and that, judging from results obtained at Zollern I and II, and providing sufficient pumping capacity, it should be possible to employ it with a flow of water amounting to 15 cbm. (3960 galls.) per minute. He adds that in neither of these shafts was any one hurt by rock falling from the sides.

Apprecht, in his description, lays stress on the avoidance of wedging-cribs, which are costly and cause much delay; also, on the saving in time and expense of timbering, and specially on the possibility of shutting off the water completely at almost any point and at any time. This prevents injury from sudden inrushes of water, such as may easily occur when from 15 to 25 m. (49.2 to 82 ft.) of the shaft are devoid of lining because no satisfactory stratum may have been found on which to base a wedging-crib.

Bergmeister Wiesmann, general manager at Emscher-Lippe, emphasizes this point in connection with the two shafts which were sunk on that property. One of them, which was lined with wedging-cribs and tubbing to a considerable height, had to deal with 6 to 7 cbm. (1584 to 1848 galls.) of water per minute, while in the other, closely adjoining it, there was only ½ cbm. (132 galls.) per minute. It is supposed that this moderate flow was in some degree due to the use of suspended tubbing, which made it possible to hold back any flow of water at comparatively short

intervals.' It is to be remembered that, during construction, shafts sunk in this way are always completely lined from the top down, with the exception of a height of 1½ m. (4.9 ft.) at the bottom. They possess the added advantages that, in case of being flooded, a general collapse need not be feared; also that the completed shaft is free from all timbering, so that, if necessary or desirable at any time, the method of sinking may readily be changed. These conditions are particularly important when the formation penetrated contains soluble salts or consists of clay, both of which materials are notoriously difficult to deal with when the ground is wet.

Proceeding to the question of shaft-sinking in heavily water-bearing ground, which may be either hard and firm or more or less in the form of quicksand, it is to be noted that there has been but little change in method. There is still the choice of the three well-known processes: drop-shafts, shaft-boring, and freezing. While numerous and very satisfactory improvements have been made in the details of these methods, which will be referred to in the following chapters, the absence of fundamental innovations is noteworthy, in consideration of the extraordinary activity in mining of the last few years, and the numerous shafts which have been put down for rock-salt, coal, and potash salts. This activity, together with the necessity for increased speed of sinking to keep pace with the commercial demand for the products, has resulted in earnest endeavors to discover new methods as well as to improve those already known. The continued increase in the diameter and depth of shafts, and the opening up of mineral deposits overlaid by great thicknesses of unstable, water-bearing soils, by which active exploitation has been hindered, and the difficulties of mining materially increased, have compelled attention to any

promising improvements. Of the numerous suggestions, and the small number of really interesting and original inventions, some of which have been patented, but few have been applied in actual practice. The latter will be dealt with in detail in the following chapters, specially those improvements which relate to the three processes mentioned above.

As compared with sinking by ordinary hand-work, all of these three methods are slow and costly. Valuable data and comparative figures concerning them have been published in the "Festschrift zum VIII deutschen Bergmannstag, 1901", by Bergassessor Koehne, in the chapter on shaft-sinking methods. In the number of *Glückauf* dealing with the proceedings of the Eighth Convention of German miners, considerable useful information is contributed by Bergassessor J. Hoffmann, of Essen.

In making this comparison, however, it must be remembered that the three methods to be discussed can be applied advantageously only when the flow of water is so great or the material to be sunk through of such a nature that hand-work becomes impossible. Sinking by hand will have the preference, both because of its efficiency and lower cost, in every case where it can be used at all, even though the flow of water be considerable. Its advantages are so great that even the freezing process, so much in use for heavily water-bearing formations, is based on temporarily converting the ground to be traversed into a state which permits of hand-work. In spite of the tedious and elaborate operations required and the time lost in the actual freezing, this system has proved eminently satisfactory, simply because it enables hand-work to be done expeditiously in a solid mass of frozen ground.

II.

SHAFT-SINKING BY BORING.

THE method of sinking an entire shaft in a single boring operation, carried on under water, was first introduced by Kind. Originally the whole cross-section of the proposed shaft was bored in one operation by the only means then available, viz., the percussion- or drop-drill. The procedure was merely an extension of that followed in sinking artesian wells. Later, the plan of drilling an advance bore, by a small tool or trepan, from one third to one half the full diameter of the shaft, was frequently adopted, because it was easier to remove the drillings and to keep the shaft plumb. The shaft section was completed by a large trepan, which took out the ring-shaped area remaining. As its cutting edges sloped toward the middle, the drillings readily ran off into the central advance bore, so that the trepan always worked on a clean surface. This system, as used at the present time under normal conditions, will now be described and illustrated.

The boring method is applied only after a portion of the shaft has been sunk by hand-labor and ordinary pumping, and when no further progress by these means can be made. In cases where large quantities of water are anticipated, the adoption of the boring system would usually be a foregone conclusion. Everything is then arranged from the beginning so

that the plant can be installed with the least possible difficulty and expense. The head-gear must be so designed that it can be used as a derrick for the boring-tools, or at least can readily be altered for such purpose; the shaft must be free from timbering, stationary pumps, etc., and the shaft equipment so constructed that all can be quickly raised to the surface in the event of unexpected flooding. Furthermore, the inner surface of the shaft-lining itself must be smooth whether it be masonry or tubbing, and the supports for such lining must in no case protrude into the shaft beyond the general cross-section. If these precautions be not taken and the shaft should unexpectedly be drowned out, the only remedy is to plug the bottom with concrete and, after it has hardened, to pump out the water and remove the interior fittings. This done, a small excavation, 3 or 4 ft. deep, is made in the middle of the shaft bottom, sufficient in diameter to admit the small trepan and guide it in the subsequent boring. The shaft is then allowed to fill again with water, the surface equipment meanwhile being altered as required for the boring-plant.

To permit of convenient handling of the rods, which are usually in 20-m. (65 ft.) lengths, the derrick or boring-tower must be of considerable height. It should also be substantially built, as the weights dealt with are large. On opposite sides of the derrick itself two large wings are built, the whole structure thus resembling a long high room. (Fig. 1, from a photograph, shows the exterior of such a building.) It contains two longitudinal tracks, one above the other. The upper and narrower track, placed immediately under the roof, is designed for the travelers or carriages from which are suspended the drill-rods and for shifting and bringing them into position. The lower track, of broader gauge, carries the trucks for supporting the

Fig. 1.

trepans, sand-pump or sludger, and the various grappling apparatus, by which these tools are readily moved as required to and from the mouth of the shaft. Plates III and IV represent longitudinal and cross sections through the boring-tower and wings. In these plates *a* is the large and *b* the small trepan; *c* the sludger ordinarily used; *d* a scraper, to clear the shaft bottom of pieces of iron, drill-bits, etc., which may have fallen in; *e* a grappling-hook for recovering broken rods; *f* are the rods themselves; *g* the trucks for carrying them; and *h* is the drill-truck for carrying the trepans. In Plate III, *i* represents the engine for raising and lowering the trepans and rods, and *k* a similar engine for the sludger, by which the debris is removed from the shaft.

Power for operating the trepans is furnished by the steam-cylinder *l*, the simple valve-motion of which is controlled by hand. This engine actuates the walking-beam *m*, which raises and drops the rods and trepan. Between the supporting chain and the rods is the temper-screw *n*, placed at a convenient height above the driller's platform. This device, operated by hand by the turning-lever *o*, serves to rotate the trepan as well as to lower it gradually as the shaft is deepened. The two following cuts show the form of drill or trepan now used; it is made entirely of steel. Fig. 2 is of a small trepan weighing about 10,000 kg. (22,000 lbs.), and Fig. 3 a large one of some 24,000 kg. (52,800 lbs.).

Drilling is usually begun with the small trepan, which, as a rule, is operated alternately with the large tool, the latter enlarging the shaft to the full section. It is best to keep the small center bore a certain distance in advance of the enlargement, so that drillings may readily collect therein and be removed by the sludger. The work of drilling and of operating

the sludger proceeds alternately. The trepans are inspected at the surface after each run, loose parts or joints tightened up, and the bits or teeth changed when dull. The time required for cleaning out the debris is usually sufficient for this inspection and adjustment. For large-scale operations in deep shafts it is customary to have two trepans of each size, in order to avoid all unnecessary delays.

The boring of the shaft is continued through the water-bearing formation into an impervious stratum, below which no further large flow of water is to be expected. One of the chief dangers involved in this work is the risk that the shaft walls may cave. This is most likely to occur when passing through loose, broken formations, or sandy and clayey strata, or quicksands. The remedy is to line the weak places with plate-steel casing, which must be supported either on a shoulder left in the shaft walls or else suspended from the surface by wire ropes. These lining-plates need not be very thick, as they are not expected to resist much pressure, but are only temporary, to allow the drilling to proceed in the water-bearing strata. They are disadvantageous, however, as they reduce the net shaft area. It is therefore advisable to allow for the possible necessity of such lining, when deciding upon the original diameter of the shaft to be sunk.

When the shaft has reached the underlying impervious stratum already mentioned, the bottom is carefully cleaned of all drillings, the boring-tools removed, and the derrick arranged for lowering the cuvelage; that is, the permanent water-tight lining, which is composed of cast-iron rings. In lowering the cuvelage, which, for deep shafts, is of great weight (sometimes amounting to 4000 tons), advantage is taken of its buoyancy. The two lowermost rings are so constructed that

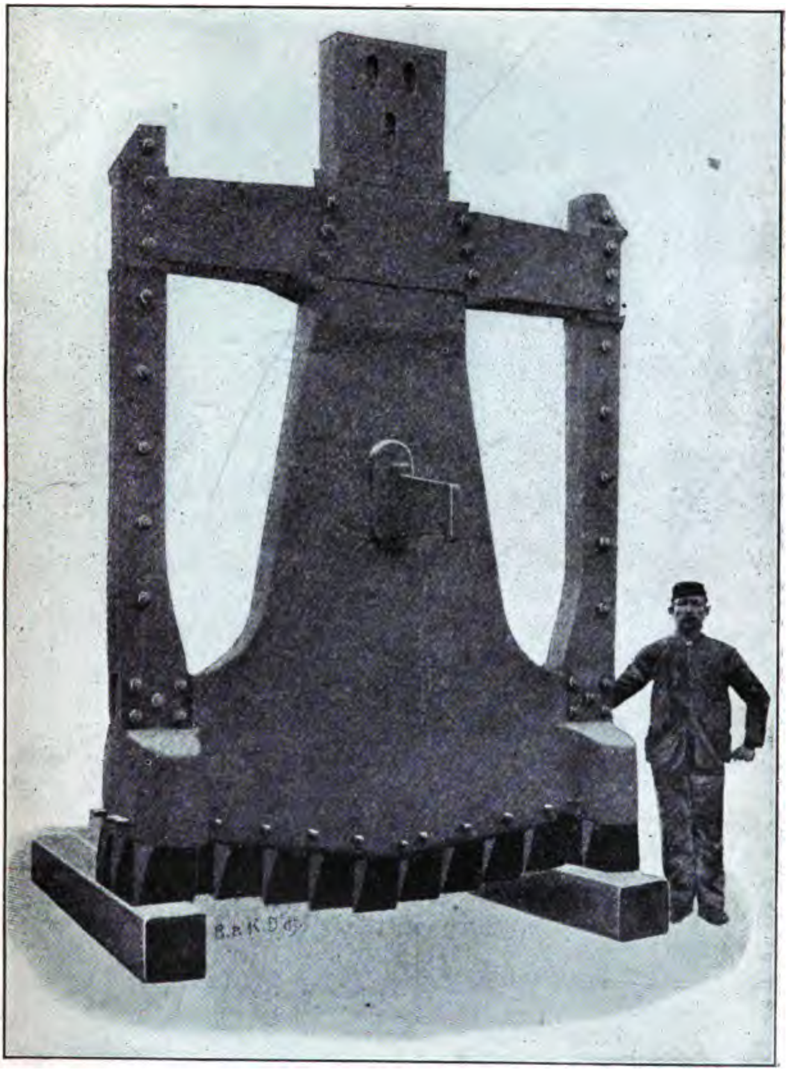

FIG. 2.

FIG. 3.

they can telescope into each other, thus forming in effect a huge stuffing-box. The outer annular space between the flanges of these rings is filled with moss, the whole arrangement being called the "moss-box". When the lining reaches its seat in the solid stratum at the bottom of the shaft, the lower rings slide into each other, thereby compressing the moss and forming a water-tight joint between the lining and the shaft walls. The water in the loose strata above is thus shut out.

Preparatory to erecting the shaft-lining, a strong platform is built immediately over the collar of the shaft. On this are placed in position the two rings constituting the moss-box. The space between their lower flanges is packed with moss, which is then covered with a strong wire netting, so that the moss cannot fall out while the lining is being lowered. The first ring of the lining proper, with the accompanying bottom or closing diaphragm (see Plate V), is then bolted on top of the moss-box, and the entire apparatus suspended directly over the shaft by means of six or eight heavy rods. The rods in turn are attached to powerful lowering-screws mounted at some height above the shaft-collar. Fig. 4 represents a complete moss-box, with its inner diaphragm, suspended from the rods as described. After it has been raised slightly from the platform, the latter is removed and the moss-box lowered by the screws until the upper flange is slightly below the collar of the shaft. Then the lowering-rods are fastened by clutches to temporary cross-timbers at the shaft mouth, the upper part of the rods uncoupled, and a new ring brought into position. The rods are now coupled up inside the last ring, after which the supporting timbers are removed, and the new ring lowered into place and bolted fast. From time to time the rods are lengthened by additional sections. These operations are re-

peated for each ring. Ultimately the lower end of the lining with the moss-box reaches the water level, after which the weight is more or less counterbalanced by the buoyancy of the closed lining.

Plate V, left-hand side, shows the earlier stages of the lowering operations to which the above outline description refers. As soon as the buoyancy of the lining, due to increased displacement, overcomes its own weight, the lowering-rods can be dispensed with and the work is thenceforth simpler and proceeds more rapidly. Finally the buoyancy will exceed the weight of the cuvelage, which must then be weighted in order to lower it farther. This is usually accomplished by partially filling it with water introduced through stop-cocks in the central "equilibrium pipe". In the case of a shaft which has been sunk entirely by boring, and which therefore must be lined throughout its entire depth, ring after ring is added to the cuvelage until the moss-box rests on the bottom. A sufficient quantity of water is then admitted to the cuvelage to weight it so that enough pressure is exerted on the moss-box to compress the moss, force it solidly against the shaft walls and thus make a water-tight joint.

The next step is to install the apparatus for concreting the entire annular space between the cuvelage and the walls of the shaft. For this work it is customary to use four wide, flat boxes, with bottoms opening outward, which are filled with concrete and lowered with rope guides. After allowing from four to six weeks for the concrete to set, the shaft is pumped out and the false bottom of the cuvelage, with the equilibrium pipe, removed. Further sinking then proceeds by hand-work. As already stated, shaft-boring is rarely resorted to nowadays until a certain portion of the shaft has already been completed and permanently cased with some form of lining.

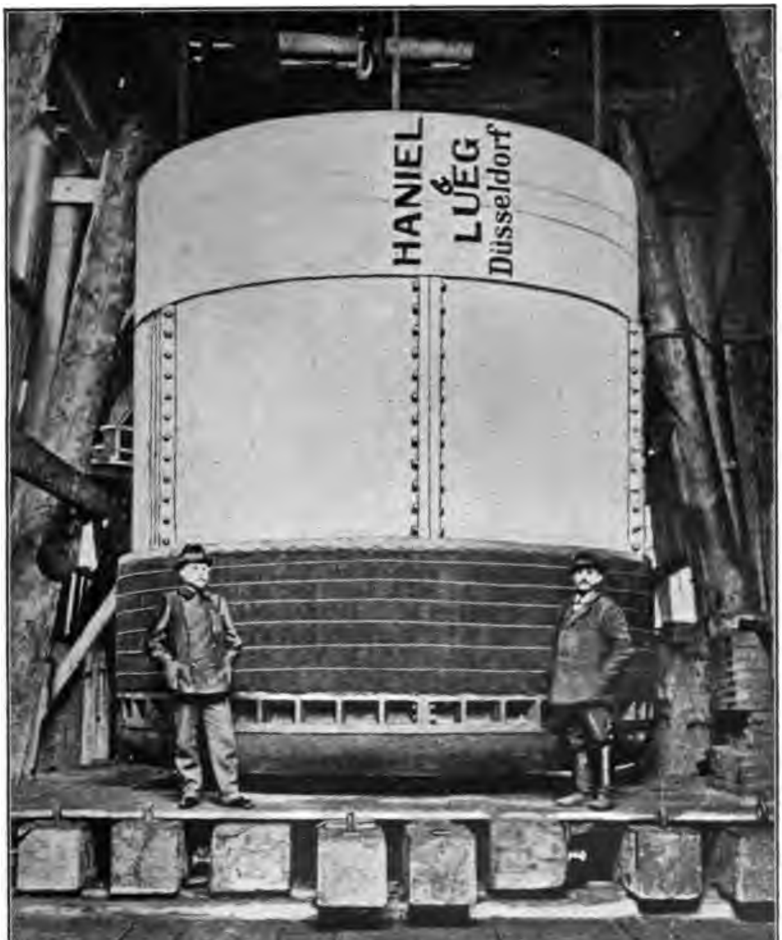

FIG. 4.—Assembled moss-box, with the bottom ring.

It is not always necessary to carry the cuvelage above the level of the water in the shaft; as a rule it suffices to build it high enough to overlap part of the upper permanent lining. In such cases a water-tight cover is bolted to the top of the cuvelage. This is resorted to when a sufficient number of rings have been added to reach to the top of the water-bearing strata, after which the cover is put on in precisely the same way that the false bottom of the cuvelage was installed. The entire cylinder is then lowered to the bottom of the shaft by means of rods or ropes and lowering-screws, just like a well-closed bottle, sufficient water ballast being first admitted to cause it to sink properly. Concreting is then applied as already stated, though of course only as high as the upper edge of the cuvelage. Plate V, right hand, shows such an installation, the lining resting on the bottom and the concreting completed. The cut illustrates the work at the shaft of the "Kaliwerke Benthe, Aktien-Gesellschaft", in Hanover.

In the foregoing description many minor details have been omitted for the sake of brevity. In concluding this general outline of the method, a sketch of the history of its development in Germany may be useful, after which a more detailed description of certain interesting examples of its application will be given.

But little interest in the Kind-Chaudron system of shaft-boring was evinced in Germany until General Manager Schulz-Briesen published, in 1879, a description of the operations at Dahlbusch, in the "Zeitschrift für das Berg-, Hütten- und Salienwesen im Preussischen Staate." Up to that time 18 shafts had been sunk by boring in France, 12 in Belgium, 4 in England, 5 in Lorraine, and 5 in Westphalia. All those in

Westphalia belonged to the Dahlbusch Mining Company, which may well claim to have been the leader in the application of this method. The depths of these shafts varied from 88 to 107 m. (288 to 351 ft.). As a rule they passed through marls, which were easy to bore and permitted of rapid progress.

Since then many shafts have been sunk in Germany by this process, though in none of them was boring started until the work had reached a certain depth and difficulties had accumulated to such an extent that all other methods had failed, or at least showed no prospect of succeeding. In all these cases boring proved a pronounced success; in fact, no shaft in which the method has been employed has had to be abandoned while under construction. It may be added that in one case boring was not completed, viz., at the Segengottes shaft, Mansfeld, where, as was ultimately discovered, the conditions prevailing did not really necessitate the use of the method.

General Manager Tomson deserves much credit for making the Kind-Chaudron system better known, since he used it with success at shafts I and II, of Gneisenau. In shaft I the water was finally shut off, between the years 1882 and 1885, at a depth of 240.6 m. (790 ft.), and in shaft II, between 1884 and 1886, at a depth of 244 m. (800 ft.). Covering the top of the cuvelage for sinking it below water-level, in order to reduce its length, was first tried at this mine. Both shafts had originally been sunk by hand to a depth of 105 m. (345 ft.) and were then abandoned on account of the large inflow of water.

Shaft-boring was also carried out successfully at the Clotilde shaft of the Mansfeld Company between 1884 and 1887, at shaft II of the Herzogliche Salzwerksdirektion, in Leopoldshall,

between 1887 and 1889, and at shaft I of the Thierderhall Company, near Brunswick, in the years 1887 to 1889. The latter shaft is of general interest in that the conditions prevailing were particularly difficult and the heavy flow of water continued until the rock-salt deposit was struck. Here for the first time the water was successfully dammed back in the rock-salt itself, a procedure previously considered impracticable.

In 1891 the production of the Rhenish Westphalia collieries increased to such an extent that larger shafts became an absolute necessity. Up to that time difficulties involved in manufacturing and transporting cast-iron rings for the lining of large shafts had limited their diameter to 3.65 m. (12 ft.) in the clear, which was probably one of the chief reasons why the mining companies always avoided such work except as a last resort. At the suggestion of General Manager Tomson, Haniel & Lueg undertook the modernizing of their railroad equipment so that tubbing-rings 4.1 m. (13.5 ft.) in diameter and 1.5 m. (4.9 ft.) high would pass through the standard cross-section fixed by the railway. By these means and by sectionalizing the exterior ring of the moss-box, another suggestion of Tomson's, it became feasible, in boring shaft I of the Preussen No. 1 colliery, to install a cuvelage 4.1 m. (13.5 ft.) diameter in the clear, between 250 and 342 m. (820 to 1122 ft.) below the surface. This enlargement of the shafts and the increasing depths necessitated better and more powerful boring-plants. The old-time oak walking-beams, bound with iron, were replaced by those of the riveted iron-girder type, and although no radical changes were made in the construction of the other tools, they were materially strengthened. The diameter of the smaller or advance trepan has been increased

from 1.4 to 2.5 m. (4.6 to 8.2 ft.) and the enlarging trepan, of 4.8 m. (15.75 ft.) diameter, so constructed and strengthened as to enable it to withstand the severe shocks incidental to its operation. The drill-rods formerly 16 m. (52 ft.) long are now made in 20-m. (65 ft.) lengths, to save time in raising and lowering them.

An important improvement has been made in the method of lowering the cuvelage. It was formerly the custom, particularly in the case of shallow shafts, to lower by means of six lowering-screws placed in the boring-derrick. For great depths such procedure would require the use of six very long and expensive lines of rod. At the Preussen mine, after the closed top or cover was put on the cuvelage, the rods were replaced by a single hook and yoke, patented by Chastelain, chief engineer of the Kind-Chaudron Company, and which had done good service at Ghlin. The apparatus is attached to the regular drill-rods, and the cuvelage, after the cover has been put in place, is lowered to its permanent position by the hoisting-engine and rope. (See Plate V, right hand.) This device has been so satisfactory that it has come into general use in all deep shaft-boring operations.

DESCRIPTIONS OF ACTUAL PRACTICE IN SINKING SHAFTS BY BORING.

BORING THE SHAFT OF THE POTASH MINE AT JESSENITZ. (PLATE VI.)

IN 1893 work was resumed by the "Mecklenburgische Kalisalzwerke" on their shaft at Jessenitz. The work of sinking here has probably consumed more time than any other modern shaft. Both the persistency exhibited and the expense incurred in completing it were unprecedented. Difficulties of every kind were encountered, and the means employed to overcome them are worthy of general attention.

The following strata were passed through:

0– 19 m. (62 ft.)	sand
19– 36 m. (62–118 ft.)	fine and coarse gravel
36– 43 m. (118–141 ft.)	gypsum, with interstratified sands
43– 68 m. (141–223 ft.)	gypsum, varying in hardness
68–142 m. (223–466 ft.)	hard gypsum
142–146 m. (466–479 ft.)	fissured gypsum with clay
146–153 m. (479–502 ft.)	fissured sandstone
153–270 m. (502–986 ft.)	gypsum and anhydrite
Below 270 m. (986 ft.)	rock-salt

The Poetsch freezing process was adopted for sinking through the upper water-bearing strata. After the ground was frozen, sinking was carried on without incident to a depth of 75 m. (246 ft.) At that point a wedging-crib was put in, and a series of German machined tubbing-rings built up to the collar of the shaft. Sinking by hand in the ordinary way was then started in the bottom. A second wedging-crib became imperative at the depth of 89 m. (292 ft.), as the upper one allowed an inflow of 20 liters (5.3 galls.) of water per minute as soon

as the ground had thawed out. The installation of the second section of tubbing, between 89 and 75 m. (292–246 ft.) rendered the shaft completely water-tight, so that sinking was carried to 130 m. (426 ft.) without further inflow. At the latter point the neighborhood of fissured strata was reached, which, by the results obtained from the preliminary bore-holes, were known to carry much water.

As the entire Poetsch equipment was still available, it was decided to freeze the ground and then sink through it from a depth of 130 to 175 m. (426 to 574 ft.) The freezing-pipes were accordingly put down at regular intervals just inside of the shaft-lining. They were 170 mm. (6.6 ins.) in diameter, 10 mm. (0.4 in.) thick, and sunk to a depth of 175 m. (574 ft.) The result was unsatisfactory; the frozen cylindrical wall proved so leaky that the shaft was flooded. Pumps were then installed, but in spite of al efforts it was found impossible to sink below the 150-m. (492 ft.) mark. Pumping was continued for several weeks without success. Th water-level occasionally rose to a point 8 m. (26 ft.) below the collar of the shaft, and at no time could it be lowered to more than 40 m. (131 ft.) below the surface.

Not until ten years' vain effort had convinced the management of the impossibility of success by these means was it decided to try sinking by boring. Unfortunately, the abandonment of the work in the bottom had been so hasty that almost all the tools, buckets, and other articles of iron or wood had been left in the shaft. Moreover, the freezing-pipes were still in place, each 35 m. (115 ft.) long. The importance of the removal of the latter was fully realized, as it was evident that they would seriously obstruct boring operations.

After concreting the shaft bottom to a depth of 13 m. (43 ft.),

which effectually closed all water-bearing fissures, and all timbering, pumps, bearers, etc., being removed, an attempt was made to pull the freezing-pipes. It was a complete failure, probably because the pipes were broken and bent. Attempts made to cut out these pipes by drilling around them also failed, probably because they were materially out of plumb, as was subsequently learned. After several months had been lost in similar abortive efforts, it was finally decided to bore the shaft without reference to such obstacles, and to remove the pipes during the progress of the work. The boring-plant was of the usual design. As might have been anticipated, boring became difficult after cutting through the concrete in the sump, partly because of the steep dip of the strata and their fissured condition, partly because some of the freezing-pipes protruded into the shaft. Several of the pipes were cut lengthwise by the trepan so that pieces remained standing upright, which hindered the rotation of the trepan, often forcing it to one side and throwing the shaft out of plumb. Tedious trimming of the shaft walls, by means of special saw-like teeth set in the trepan, was frequently necessary in order to rectify the work.

Much faster progress was made below 175 m. (574 ft.), i.e., after passing below the ends of the freezing-pipes. Down to that point 11 tons of wrought iron and steel had been broken into small pieces by the trepan and brought to the surface by the sludger.

As shown by the test borings, the solid gypsum occurred at a depth of 175 m. (574 ft.), so that it should have been possible to dam back the flow of water at that horizon. In order to be absolutely safe, however, Haniel & Lueg suggested that the underlying strata be tested for water. A line of pipe was run from the surface to the bottom of the shaft and its lower end

for a height of 2 to 3 m. (6.5 to 10 ft.) was filled with concrete. After the concrete had set, the pipe was pumped out and drilling inside of it started with a diamond drill. At 211 m. (692 ft.) water was encountered which filled the entire pipe. It was, however, uncertain whether the water came from the rock or from a defective portion of the pipe. In order to settle this question, the bottom of the bore-hole in the pipe was again concreted, between 218 and 200 m. (715 and 656 ft.), and after it had set the water was pumped out to a depth of 43 m. (141 ft.) without any indication of its rising again, so that the presence of water in the strata at the bottom of the bore-hole was evident. This being settled, work in the shaft was resumed, using alternately the advance and the enlarging trepans.

After the smaller bore had reached a depth of 252 m. (827 ft.) and the enlarged section 201 m. (660 ft.), the ground ahead was again drilled, with results similar to those described above. The enlargement was then continued to the 255-m. (837-ft.) level, and at this point, 6 m. (19.5 ft.) above the rock-salt, still another test was made for water.

Unfortunately the ground immediately above the salt proved both wet and crumbly, and much given to caving. Under these circumstances nothing remained but to advance the shaft-boring 20 m. (65 ft.) or so into the rock-salt itself and to set the moss-box at that point. Salt was encountered at a depth of 261 m. (856 ft.), and drilling was stopped at 287 m. (941 ft.) On testing the shaft with a wooden template, in order to ascertain if it were large enough throughout to permit the cuvelage to pass, the unpleasant discovery was made that the sump was filled to a depth of some 5 m. (16 ft.) with caved ground. It was feared that, in lowering the cuvelage or in the subsequent cementing, further caving might cause a com-

plete failure of the work. To avoid this it was decided to line the shaft from the salt at 260 m. (853 ft.), for a height of 50 m. (164 ft.), with a plate-iron cylinder. As this lining could not be inserted in one piece, it was lowered in two sections, each about 27 m. (88 ft.) long. On attempting to lower the first section, which was 4.756 m. (15.6 ft.) in diameter, 27.8 m. (91 ft.) long, 16 mm. (0.62 in.) thick, and weighed 62,500 kg. (137,500 lbs.), it jammed at 194 m. (636 ft.), probably because of a small deflection in the shaft. As repeated raising and lowering of the lining had no effect, it was raised to the surface and cut in two, after which the lower portion passed the obstruction without further difficulty. It was finally brought to rest on the narrow shoulder or seat at 263 m. (862 ft.) No more lining was put in, as it was generally conceded that the caving had taken place immediately above the rock-salt, which was thus secured by the portion of the lining actually inserted.

The cuvelage, 4.1 m. (13.5 ft.) in diameter, was then put in place and concreted. (Plate VI). After allowing time for the concrete to set, pumping was started, but it soon became evident that the water had not been successfully shut out, as it began to flow into the shaft through the equilibrium-pipe. Soundings in the latter showed that the space below the false bottom of the lining was filled with gypsum, which had caved from the sides of the shaft. The origin of this material was uncertain; that is, whether it came from the ground immediately above the short section of temporary lining and had caved just before or simultaneously with the first concreting, thereby destroying its usefulness, or whether, because of the steep dip of the strata or the unevenness in the surface of the rock-salt, the cuvelage had not been sunk quite deep enough, thus allowing a break to take place underneath. All attempts to bail

out the water were unavailing; its level remained stationary at 50 m. (164 ft.) below the surface.

The sole remaining possibility of completing the shaft was to lower a smaller cuvelage inside the first, to do which it would be necessary to bore 30 m. (98 ft.) or so deeper. In order to dam back the water, so that the equilibrium-pipe could be removed, the space below the false bottom of the cuvelage was concreted by lowering the material in boxes through the equilibrium-pipe itself. On setting, the concrete cut off the water coming under the moss-box, so that the shaft could be pumped out and the equilibrium-pipe removed down to the false bottom.

These preliminaries being completed, boring was resumed with a 2½-m. (8.2-ft.) trepan, followed by another measuring 3.95 m. (13 ft.) in diameter. The false bottom, weighing 15,000 kg. (33,000 lbs.), which could not be removed because of the flow of water, was cut out and in five months the additional 30 m. (98 ft.) of shaft was bored, making a total depth of 310 m. (1017 ft.)

A new cuvelage, 3.15 m. (10.3 ft.) inside diameter and 39 m. (128 ft.) high, was then readily lowered. Much care was taken in concreting behind the cuvelage, an arrangement being adopted whereby all four concrete boxes could be emptied simultaneously. The lowermost 6 m. (20 ft.), immediately above the moss-box, were filled with magnesia cement, the remainder with ordinary concrete. After the concrete had hardened and the water had been pumped out, the shaft appeared to be absolutely water-tight. The bottom and top of the second cuvelage were then removed and the connection between it and the wedging-crib completed in a perfectly dry shaft.

This brought to a satisfactory conclusion work which had

lasted sixteen years. Sinking by boring had begun March 6, 1894, at a depth of 141.3 m. (463 ft.), and the final shutting off of the water was completed February 1, 1900. The boring of the lower 170 m. (558 ft.) of shaft consequently occupied five years and eleven months, while the upper 150 m. (492 ft.) cost ten years' work. Plate VI shows the completed shaft, with the two cuvelages and the lower tubbing connections.

Operations at this shaft again showed conclusively that a water-tight connection can be made with absolute certainty in rock-salt, and that its accomplishment is by no means dependent on fortuitous circumstances, as had been thought by many experts when the Thiederhall shaft was sunk. Doubts as to its feasibility had also been expressed when the Beienrode Company encountered salt water in sinking their shaft, which eventually led to the abandonment of the work and the sinking of an entirely new shaft. But such questions have now found a satisfactory answer in the results of the work at the Jessenitz shaft, as well as at the shaft of the Benthe potash-mines, which were sunk under conditions similar to those at Beienrode, and plainly demonstrated the possibility of effecting a water-tight connection in the rock-salt itself.

Boring of the Adolf von Hansemann Shafts. (Plate VII.)

The work on the Jessenitz shaft was followed in the years 1896 to 1898 by the boring of shafts for the "Bergwerks-Aktien-Gesellschaft La Houve", at Kreuzwald, the "Gewerkschaft Victor", at Rauxel, and the Adolf von Hansemann mine, of the "Mengeder Bergwerks-Aktien-Gesellschaft".

At both the Victor and the Adolf von Hansemann shafts the cuvelages measured 4.4 m. (14.5 ft.) inside diameter. Although

carried on specially designed trains, the transport of entire rings of this size was rendered possible only by the courtesy of the railroad management at Essen, in temporarily lowering the permanent way by 0.3 m. (1 ft.) at overhead crossings.

The sinking of shaft III at the Adolf von Hansemann mine was preceded by interesting sinking operations in other shafts of the company, which are worthy of note as they so clearly demonstrate that under difficult conditions boring is after all the cheapest method. Shaft I, which was begun in 1873, by the ordinary methods, took thirteen years to reach a depth of only 230 m. (755 ft.) on account of the endless difficulties encountered. The chief trouble was due to the large quantity of water to be pumped, and, as attempts to shut it off failed completely, the shaft was abandoned in 1886.

Shaft II was started in 1888, some 200 m. (656 ft.) south of shaft I. Here fortune favored the company, as the volume of water was not too great to be readily held in check by pumping. But, though the maximum flow was only 7 cbm. (1850 galls.) per minute, the other difficulties were so great that it was five years before the coal-measures were reached.

After completing shaft II, work was resumed on shaft I with the aid of the pumps in No. II. A drift was run under shaft I from No. II and a raise put up as high as the condition of the country rock permitted. A masonry dam with a drain-pipe was then built in the drift, so that the water from shaft I could be drained through No. II. Finally a bore-hole was put down to the drift from the bottom of the shaft. Shaft II had been provided with simple, direct-acting lift-pumps. As an extra precaution, these were replaced with plunger-pumps having a capacity of 10 cbm. (2640 galls.) per minute. The latter were supplemented by a large Woolf pumping-engine of 5

cbm. capacity, erected at shaft I, and a small underground pump at shaft II. With these pumps the water was kept down for a short time, but on sinking farther the inflow increased to 40 cbm. (10,560 galls.) per minute, so that the work had to be abandoned.

On August 8, 1894, shaft III was started 200 m. (656 ft.) north of No. I. The strata to be traversed were much the same as in shafts I and II, viz.:

Quicksand	0 to 7.5 m.	(0– 25 ft.)
Green marls	7.5 to 221.5 m.	(25–727 ft.)
Upper greensands	221.5 to 225.0 m.	(727–738 ft.)
White marls	225.0 to 251.5 m.	(738–825 ft.)
Lower greensands	251.5 to 254.5 m.	(825–835 ft.)
Coal-measures	below 254.5 m.	(835– ft.)

In the quicksand above the marls a drop-shaft was put down, and then, in carrying on the sinking by ordinary means, the small amount of water coming in was shut off with German tubbing down to a depth of 45 m. (147 ft.). Below that point the shaft was lined with masonry. (Plate VII.)

At 190 m. (623 ft.) a fissure was cut which carried 1½ cbm. (400 galls.) of water per minute. As there had been a very large inflow in shaft I at this depth, a considerable increase of water had already been anticipated in shaft III. In order to deal with it, sinking was stopped and a drill-hole put down to the drift which had been run under the shaft on the 273-m. (895-ft.) horizon. This hole was 230 mm. (9 ins.) diameter and was bored in six weeks. When sinking was resumed the water soon increased to such an extent that the bore-hole proved to be too small, and was therefore enlarged to 270 mm. (10½ ins.) diameter. After deepening the shaft another 0.5 m. (1.6 ft.), work was abandoned, as the water had increased to 22 cbm.

(5810 galls.) per minute—the full capacity of the pumping-plant.

Before stopping operations the shaft was stripped, cleaned out, and the dam in the drift below closed. Arrangements were then made at the surface for installing the Kind-Chaudron system of boring. The construction of the derrick and erection of the machinery occupied 3½ months.

On August 10, 1896, the water in the shaft stood at 53.4 m. (175 ft.), and boring was started at a depth of 195.35 m. (640 ft.) with a trepan 2½ m. (8.2 ft.) in diameter. The coal-measures were reached on December 8th at a depth of 255 m. (833 ft.). In round numbers, therefore, about 60 m. (197 ft.) were made in four months, the daily progress, including all stoppages, being 0.5 m. (1.64 ft.), and the maximum advance in any single calendar month, 18.22 m. (60 ft.).

On December 18, 1896, the work of enlarging the shaft to full size was started at a depth of 195.5 m. (641 ft.), with a trepan 5.02 m. (16.5 ft.) in diameter. The enlargement was successfully completed November 19, 1897, at a depth of 253 m. (830 ft.), equivalent to an advance of about 58 m. (190 ft.) in eleven months; or an average of 0.176 m. (0.58 ft.) per twenty-four hours, with a maximum advance of 7.8 m. (25.6 ft.) in a single month.

The boring-plant was dismantled between December 19, 1897, and January 2, 1898, and preparations made for lowering the cuvelage. This was provided with false bottom and cover and consisted of fifty-seven rings, 4.4 m. (14.5 ft.) in diameter, 1.2 m. (3.9 ft.) high, and from 68 to 86 mm. (2.6 to 3.3 ins.) thick. (Plate VII.) Work on the cuvelage was begun January 2, 1898, and ended March 4th. Between March 15th and April 15th the cuvelage was concreted, and six weeks later,

on May 23d, pumping was started. The cover and false bottom of the cuvelage were duly removed, and on reaching the moss-box, June 21st, it was found that all water had been completely shut off. A few meters more were sunk by hand, for putting in the closing-rings, which work occupied four weeks, so that everything connected with the boring operations was finished by July 20, 1898. Sinking under ordinary conditions was then resumed. The total time occupied in boring was about 22 months, equivalent to an average advance of 2.73 m. (9 ft.) per month.

Shaft-sinking at Kaiseroda. (Plate VIII.)

The shaft of the Kaiseroda Company is at Tiefenort, near Salzungen on the Werra. Work was begun in the usual manner by hand, the water being raised by pumps. The shaft is 5 m. (16.5 ft.) diameter in its upper portion and lined with masonry to a depth of 34.8 m. (114 ft.). Below that point English tubbing was used. The preliminary bore-holes showed:

Loam	0 to 2 m.	(0– 6.5 ft.)
Buntsandstein	2 to 120 m.	(6.5–394.0 ft.)
Marls (brittle)	120 to 166 m.	(394 –543 ft.)
Water-bearing shaly dolomite	166 to 176 m.	(543 –576 ft.)
Variegated clays with stringers of gypsum	176 to 205 m.	(576 –672 ft.)
Gray rock-salt	205 to 207 m.	(672 –679 ft.)
Anhydrite and rock-salt	207 to 219 m.	(679 –718 ft.)
Red saliferous clays	219 to 225 m.	(718 –836 ft.)
White rock-salt	below 225 m.	(836 – ft.)

The flow of water recorded was as follows:

At a depth of	8 m. (26 ft.)	0.5 cbm.	(132 galls.) per minute
" " "	34.8 m. (114 ")	1 to 2 cbm.	(264 to 528 galls.) per minute
" " "	44.3 m. (145 ")	3 "	(792 galls.) per minute
" " "	60.5 m. (198 ")	4 "	(1056 ") " "
" " "	80.0 m. (262 ")	5 "	(1320 ") " "
" " "	114.0 m. (373 ")	17 "	(4488 ") " "

On entering the brittle marls at 120 m. (393 ft.), conditions so far improved that a wedging-crib was successfully set at 129.6 m. (425 ft.) and shut out most of the water. A second crib was placed at 146 m. (479 ft.) and the shaft lined with English tubbing; but when sinking was resumed the water broke in again at 148 m. (485 ft.).

The three direct-acting pumps with which the shaft was eventually equipped were unable to lower the water, and moreover it was found that the inflowing water carried much sand which was deposited in the bottom of the shaft. Pumping was finally stopped for fear that the continued inflow of sand with the water would cause the walls to cave and so endanger the upper portions of the work.

The company then decided to try the Kind-Chaudron system of sinking, although the soft ground was unfavorable, and it was anticipated that a temporary lining would be necessary to prevent the walls from caving. No other method, however, offered any prospect of success.

Early in May pumping was stopped and the sand and mud cleaned out as well as possible from the sump, which was then filled to a depth of 8 m. (26 ft.) with concrete. After the concrete had set the shaft was unwatered and all impedimenta, such as pumps, bearers, and platforms, were removed. This work was so far completed by August 16, 1897, that drilling could be started. Two trepans, one for the advance bore 2½ m. (8.2 ft.) diameter, and an enlarging bit 4.83 m. (15.8 ft.) in diameter, were to be used. The latter was made as large as the tubbing would admit, in order to avoid losing too much area of shaft by the provisional linings which were foreseen to be unavoidable. The concrete bottom was drilled through in full cross-section with the large trepan between August 16th

and September 10th, and the advance bore started at a depth of 147.55 m. (484 ft.). By November 6th this had reached 167.24 m. (548 ft.). The ground traversed was blue and red clay, hard when dry but given to swelling when wet.

Towards the middle of October caved material was noticeable in the bottom of the advance bore. It was thought at first that it came from the walls of the advance bore itself, and therefore caused no concern, but early in November the bottom was again covered with loose material to a depth of 1½ m. (4.9 ft.), whereupon the large trepan was lowered, but failed to reach the bottom of the enlargement at 147.5 m. (484 ft.). This showed that the shelf or shoulder at this point was also covered with fallen material, which must have come from the walls above. It thus became evident that these walls would have to be safeguarded by a temporary lining, and a plate-iron cylinder, 4.73 m. (15.5 ft.) in the clear, 4.81 m. (15.75 ft.) outside diameter, and 18 m. (59 ft.) high, was put in place. It was 20 mm. (0.78 in.) in thickness and weighed 65,000 kg. (143,000 lbs.). The lower edge was sharpened, the upper edge being flanged in case it should be necessary to drive it down.

This lining was lowered January 15, 1898, after which drilling was resumed with the advance trepan, which reached the original depth of 167.2 m. (548 ft.) on March 4th. Drilling was continued with the small and large trepans alternately (the latter being somewhat reduced in size), until the bottom of the lining stood at 164 m. (537 ft.). The question of a second lining was then considered, but abandoned for the moment in the hope that the ground would stand. At 194 m. (636 ft.) further caving occurred, but the mine management was convinced that the ground had given way only in the advance bore and immediately below the bottom of the temporary

lining, and that the shaft walls at 194 m. (636 ft.) were sound enough to permit of putting in the permanent lining for shutting out the water. As the shaft bottom was close to the bed of rock-salt and the management was strongly opposed to placing the moss-box in the salt itself, it was thought that a height of 15 m. (49 ft.) of shaft would amply suffice to secure a good water-tight-joint between the lining and the shaft walls, and boring was stopped. A second plate-iron lining was lowered until its lower edge was 15 m. (49 ft.) above the bottom, i.e., at a depth of 178 m. (583 ft.). It was 15 mm. (0.58 in.) thick, 15 m. (49 ft.) high, and 4.66 m. (15.3 ft.) outside diameter. The upper 0.5 m. (1.6 ft.) overlapped the lower part of the first lining, and the whole was suspended by four flat ropes, 100×10 mm. (3.9×0.39 in.) in cross-section.

The shaft bottom was then cleaned out and preparations made for placing the permanent cuvelage in position, but on November 10th renewed caving occurred, making it necessary to extend the second temporary lining to the bottom of the shaft. For this purpose a third plate-iron cylinder was built, 4.43 m. (14.54 ft.) inside and 4.478 m. (14.68 ft.) outside diameter, 19½ m. (64 ft.) long and weighing 53,125 kg. (117,000 lbs.). The lowering began February 1st, and on the 7th the cylinder came to rest on the bottom, which was then at 191.35 m. (628 ft.), thus showing that there was some 3 m. (10 ft.) of caved material in the sump, which had previously been bored to 194.37 m. (638 ft.). This material was soon removed. In order to secure a sufficient depth of uncaved wall-surface to permit of making a proper concrete junction between the walls and the permanent lining, the shaft was drilled to a total depth of 203.5 m. (667 ft.).

Subsequent work continued without incident. The boring

plant, etc., was dismantled and work on the cuvelage commenced May 17th. This lining reached the bottom on June 5th, and the concreting was finished July 6th. Between August 15th and 26th the water was pumped out from the cuvelage, after which the cover and bottom diaphragm were removed. By September 1st regular sinking was resumed below the moss-box, the inflow of water being about 250 l. (66 galls.) per minute. Four weeks were then occupied in installing a Tomson water-hoist, so as to avoid risk of being drowned out. On resuming work it was found that the flow of water had decreased to 15 or 20 l. (4 or 5 galls.) per minute. From October 1st to November 11th 6.26 m. (20.5 ft.) were sunk by hand to the anhydrite strata and lined with closing tubbing-rings, which made the shaft entirely water-tight.

In this case, by employing the Kind-Chaudron system, 70 m. (230 ft.) of shaft were completed in twenty-seven months. This period might have been greatly shortened had the plate-iron linings been ready when needed. Much time was lost by having to order them as required, during which delays the boring was naturally at a standstill. More time was lost by having repeatedly to remove caved material, and also by the installation of the Tomson water-hoist, which eventually proved to be unnecessary. With due allowance for these adverse circumstances, the results obtained may be considered fairly satisfactory.

Boring the Preussen II and Scharnhorst Shafts.

Shaft No. 1 at Scharnhorst was begun in 1873, but after reaching a depth of 117 m. (384 ft.) was abandoned. It was not completed until 1897, the latter part having been sunk by boring. Shafts Nos. 1 and 2 of the Preussen II mine were completed in 1898. Of these, shaft No. 1, formerly known as the Bertha Wilhelmina, had reached a depth of 233 m. (764 ft.) in the seventies of the last century, when it was abandoned because of the large inflow of water. On resuming work it was bored from a depth of 233 to 372 m. (764 to 1220 ft.), shaft No. 2 of the same mine being carried down by similar means from 260 to 368 m. (853 to 1207 ft.). At the time of their completion these were the deepest shafts yet sunk by the Kind-Chaudron method.

The permanent cuvelage of shaft No. 1 is 4.1 m. (13.5 ft.) in diameter by 152 m. (498 ft.) in height, consisting of rings from 65 to 95 mm. (2.5 to 3.7 ins.) thick and weighing, with all supplementary parts, 1,560,532 kg. (3,438,410 lbs.). The lining of shaft No. 2 is 4.4 m. (14.4 ft.) diameter by 118 m. (387 ft.) high, of rings 75 to 105 mm. (2.9 to 4.1 ins.) thick and weighing, complete, 1,370,700 kg. (3,015,540 lbs.) The bottom diaphragm, weighing 22,000 kg. (48,400 lbs.), was of cast steel.

Sinking at the Mine of Aktien-Gesellschaft Benthe, formerly Gewerkschaft Wallmont, Hanover.

The Hermann shaft of this company was started April 5, 1899, about 1 km. (3280 ft.) from the village of Benthe. Hole No. 5 of the preliminary borings showed the following strata:

Soft surface soil	0 to 4 m. (0–13 ft.)
Red unctuous clay, without water	4 to 33 m. (13–108 ft.)
Red and blue clays, with bunstandstein layers	33 to 85 m. (108–279 ft.)
Red and gray clay, with gypsum stringers	85 to 170 m. (279–558 ft.)
Rock-salt	below 170 m. (558 ft.)

On May 30th a depth of 33 m. (108 ft.) had been attained by the ordinary methods of hand-work. A hoist was then installed, and work advanced so rapidly that on October 17th the rock-salt was cut at 163 m. (535 ft.). At this point a small flow of brine on the top of the salt-bed was the precursor of trouble. It carried 29% of sodium chloride and increased in volume hourly, so that the pumps, which had a capacity of 4 cbm. (1056 galls.) per minute, were no longer able to handle it. Expert advice was against any attempt to keep the water down by means of larger pumps, for fear that the shaft might cave, but strongly advocated completing the work by means of the Kind-Chaudron system, particularly as the operations at the Jessenitz shaft had demonstrated the practicability of shutting out the water in the salt-bed.

Accordingly, towards the end of October, the firm of Haniel & Lueg was entrusted with the work. At that time the shaft was lined with masonry from 130 m. (426 ft.) to the surface and with temporary lining from 130 m. to the bottom or 163 m.

(535 ft.). The diameter inside the masonry lining was 5 m. (16.5 ft.), and, the shaft being free from pumps and platforms, it was only necessary to level up the sump by putting in some 4 m. (13 ft.) of concrete for the drilling to start on. All preparations were completed early in March.

When the large trepan was lowered to sound the depth, it came to rest at 153 m. (502 ft.) instead of on the concrete at 159 m. (521 ft.). Investigation disclosed the presence of a mass of clay, which could only have come from the temporarily lined portion of the shaft above. This indicated that further caving might take place, and could be avoided with certainty only by lining the lower part of the shaft. There was, however, a bare possibility that the provisional lining might support the clay walls, so that it was decided to put the shaft down to the rock-salt in full cross-section and to await developments during that work before attempting to install a permanent lining. The accumulation of clay was then removed from the sump and work with the large trepan resumed, which encountered somewhat harder material at 157 m. (515 ft.). On April 25th the large trepan reached the depth of 166 m. (545 ft.), the shaft at that point being entirely in rock-salt. The sludger had uniformly brought up a mixture of clay and rock-salt, and no important fall of clay had been noticed. From April 25th boring was continued with the small trepan to a depth of 181.4 m. (595 ft.). During this period the drillings brought to the surface consisted of clay and rock-salt, the former predominating. This showed that the temporary lining had failed to support the walls effectually, and that a more satisfactory lining would have to be put in. It was decided to carry the boring to a finish, however, and then to lower an iron cylinder 4.9 m. (16 ft.) inside diameter, 20 mm. (0.78 in.)

thick, and $34\frac{1}{2}$ m. (113 ft.) high, for the purpose of safeguarding the shaft while installing the permanent cuvelage.

From May 11th to July 15th drilling was continued, alternately with the small and large trepans. At that time the advance bore was 197 m. (646 ft.) and the full section 181 m. (594 ft.) deep. But in the meantime rock falls had so increased that grave anxiety was felt for the safety of the upper masonry-lined part of the shaft. The large trepan had left a small bench or shoulder in the gypsum at 163 m. (535 ft.) to serve as a seat for the proposed provisional lining. On making soundings, however, it was found that this shoulder had disappeared, having evidently been undermined and washed away by the subsequent work. This serious state of affairs called for an immediate lining of the shaft. The lowering apparatus was too light to handle the entire weight (100,000 kg. = 220,000 lbs.), at one operation, so that the plate-iron cylinder had to be cut into two portions. To afford the lower section a support, the bottom of the shaft was filled with gravel to the 163-m. level. When this section reached the bottom the six supporting flat ropes, 100×10 mm. (3.9×0.39 ins.) in cross-section, were made fast at the surface, for holding the lining when the gravel was removed. These ropes also served as guides for the upper half, so that when lowered it fitted accurately above the other.

This work was completed September 15th. The spaces back of the lining caused by caving of the shaft-walls were then filled with fine slag and broken stone to avoid displacement of the lining in case of further movement. The filling was accomplished by means of a conical hood placed on top of the lining, which distributed the filling material around the sides. To prevent this filling from running out below, when removing the

gravel from the bottom of the shaft, the bottom edge of the lining was provided with hinged flaps which, during the process of lowering, would fold up and pass obstacles, but would be forced down and against the shaft walls by the filled material, the latter being thus held in place. In spite of the utmost care in planning and carrying out this procedure, the shaft was ultimately found to be forced into an oblong section, one axis being some 160 to 180 mm. (6 to 7 ins.) longer than the other; but fortunately without serious detriment, as the portion of the shaft sunk by boring had an inside diameter of 4.95 m. (16.23 ft.), which was large enough to permit of placing and concreting the cuvelage, which was to be of 4.1 m. (13.44 ft.) inside diameter.

The work of clearing out the gravel was begun September 20th, and the bottom of the advance bore, at 197 m. (646 ft.), was reached on October 15th. Boring was then continued, alternating with the large and small trepans, the former having been reduced to 4.92 m. (16.1 ft.), the latter being 2½ m. (8.2 ft.) gauge. After reaching the depths of 204 and 215 m. (669 and 705 ft.) respectively with the two trepans, boring was stopped.

On January 18, 1901, the lowering of the cuvelage was commenced, and terminated without incident March 4th. Between that date and March 29th the shaft was concreted, and eight weeks later, May 28th, after the concrete had hardened, unwatering was begun. The shaft was found to be completely water-tight, the moss-box joint in the rock-salt being entirely satisfactory. But unfortunately a further flow of water was encountered in the salt 40 m. (131 ft.) below the moss-box, which permanently drowned out the shaft and caused it to be abandoned. Plate No. IX shows the completed shaft. The importance of the work here described lies again in the con-

firmation of the idea that a shaft-lining can be rendered water-tight even in a bed of rock-salt.

Sinking the New Shaft at the K¨niglich Würtembergischen Saline, Friedrichshall, near Kochendorf, Würtemberg (Plate X).

The work at this shaft was particularly interesting, because the formation had been completely explored before its inception, and it was definitely known that water, though in considerable quantities, was likely to be encountered in two strata only, very close together, at depths of 102 and 103 m. (334 and 337 ft.). Preparations were consequently made at the start to use the Kind-Chaudron method, should it be found necessary.

Sinking was begun January 21, 1896, by hand with the aid of a windlass. On April 18, 1896, the hoist and pumps were started. The shaft was lined with machined tubbing-rings, 5.25 m. (17.2 ft.) in the clear.

After sinking to 91 m. (298 ft.) the underlying strata were investigated by a bore-hole, and on October 9, 1896, at a depth of 98.15 m. (322 ft.), water was struck. The hole was then plugged and, after sinking to a total depth of 92.3 m. (303 ft.) and completing the tubbing to this point, a pump capable of throwing 11 cbm. (2904 galls.) per minute was installed. Sinking was resumed December 16th, and at a depth of 96.75 m. (327 ft.) the underlying water, being under pressure, broke into the shaft through the remaining 1.6 m. (5 ft.) of dolomite. The flow amounted to 4 cbm. (1056 galls.) per minute, which could be readily handled. After sinking to 101 m. (331 ft.) an exploratory bore-hole was put down, encountering the second

water-bearing stratum at 102.2 m. (335 ft.), in which the water was also under considerable pressure. After plugging both bore-holes, the lower part of the shaft was lined by tubbing, to dam back the water from the upper water-bearing horizon. This was successfully accomplished January 27th.

Early in February, on cutting the lower water-bearing stratum in the shaft, the inflow proved greater than the pumps could handle. The water rose rapidly with a flow estimated at 18 cbm. (4750 galls.) per minute. As it was known to be only 1½ m. (4.9 ft.) from this point to the underlying impervious rock, where the water could be shut out by means of tubbing, it was decided to make a final attempt to push through by using larger pumps. Two of these were installed, bringing the total pumping capacity up to 34 cbm. (8975 galls.) per minute. Everything being in readiness, unwatering was started August 6, 1897. The water was successfully lowered to the 75-m. (246-ft.) level, when further progress suddenly ceased. It was probable that new channels had opened, thus admitting a larger flow. At their highest speed the pumps could not lower the water below the 88-m. (288-ft.) mark. Divers were accordingly sent down to clean up the bottom preparatory to beginning boring, and pumping was suspended. After the water had assumed its normal level, the shaft-bottom was filled to a depth of 8 m. (26 ft.) with concrete and the surface equipment for boring erected. On December 6th, preparatory to beginning boring, the shaft was unwatered to clear it of pumps, timbering, platforms, etc. This work was completed to a depth of 95.25 m. (313 ft.), and boring begun on May 3, 1898.

The ground to be traversed consisted of:

Concrete........................from	95.5 to 101.5 m.	(313–332 ft.)
White dolomitic marls................	101.5 to 102.5 m.	(332–335 ft.)
Gypsum, with clay and stringers of anhydrite..........................	102.5 to 103.15 m.	(335–337 ft.)
Gypsum and clay, alternating with layers of anhydrite.....................	103.15 to 106.25 m.	(337–348 ft.)
Bituminous clay, with stringers of gypsum	106.25 to 106.95 m.	(348–350 ft.)
Anhydrite...........................	106.95 to 107.49 m.	(350–352 ft.)
Clay, with gypsum and anhydrite........	107.49 to 108.9 m.	(352–357 ft.)
Anhydrite...........................	108.9 to 109.64 m.	(357–359 ft.)
Bedded clays, with stringers of gypsum and anhydrite.......................	109.64 to 110.54 m.	(359–361 ft.)
Hard anhydrite.......................	110.54 to 111.7 m.	(361–365 ft.)
Bedded clays, with layers of gypsum....	111.7 to 114.2 m.	(365–374 ft.)
Bedded clays, alternating with layers of anhydrite.......................	114.2 to 120.0 m.	(374–393 ft.)

The small trepan, 2½ m. (8.2 ft.) diameter, was started Mya 3, 1898, and on June 30th reached a depth of 120 m. 393 ft.), the only interruption to the work being to put down a diamond-drill hole to 148 m. (485 ft.) to investigate the water conditions. The average daily progress of the small trepan was 0.54 m. (1.77 ft.). Drilling with the large trepan, 5.2 m. (17 ft.) diameter, began July 1st and was stopped October 21, 1898, at 116.95 m. (383 ft.), the average daily advance being 0.2 m. (0.66 ft.).

The shaft was now cleaned out as far as possible, the drilling-plant dismantled and the requisite apparatus installed for putting in the cuvelage. On November 4th the erection of the moss-box was begun, lowering commenced November 14th, and the top of the lining was closed with its cover November 24, 1898. During the following night the cuvelage was successfully lowered into place, the moss-packing being compressed from a height of 97 cm. to 36 cm. (37.8 to 14 ins.). The concreting was carried on by means of six depositing-boxes, and was finished without incident on the 5th of December. Unwatering was begun about the middle of January and proved that

the cuvelage was absolutely water-tight. The cover and bottom diaphragm of the cuvelage were removed, and by January 23, 1899, the shaft was open throughout.

Sinking by hand was resumed January 25th in order to put in place the closing-tubbing rings below the moss-box. These were 2.4 m. (7.8 ft.) high. The setting of these rings, on February 15, 1899, concluded the work of Messrs. Haniel & Lueg, and the shaft, entirely water-tight to a depth of 119.35 m. (390 ft.), was turned over to the company. Subsequently, for additional security and in order to make a better connection with the lower masonry lining, another short set of tubbing-rings 3.26 m. (10.7 ft.) in height was put in place. The cuvelage was 4.4 m. (14.4 ft.) in the clear and was transported in sections by boat from Düsseldorf to Kochendorf.

The following table shows the costs of boring and lining this portion of the shaft:

	Marks.
1. Buildings, derrick, etc.	12,209.49
2. Concreting the shaft-bottom	6,462.06
3. Altering hoisting-engine on the ground for the work of boring.	16,886.70
4. Erecting and removing the boring-apparatus, tools, and materials	32,109.41
5. Boring-plant and tools purchased	57,156.75
6. Rent of boring-plant	13,024.50
7. Cuvelage and closing tubbing	62,012.94
8. Freight on cuvelage	6,893.55
9. Wages, salaries, and supplies	112,272.15
10. General expenses	2,854.38
11. Premiums and royalties	20,754.00
Total	342,635.93
Or about	$85,650.00

Allowing 42,635.93 marks as the value of such parts of the plant as could be sold, the total cost per meter for the 31.5 m. (102 ft.) of shaft between the depths of 87.95 and 119.35 m.

(288 and 390 ft.) amounted to say $\frac{300000}{31.5}=9550$ marks per meter of depth (about $735.00 per ft.). This very high price is explained by the fact that the entire cost of boring was borne by a comparatively small depth of shaft. The time consumed, from December 6, 1897, to February 15, 1899, was 14 months, equivalent to an advance of 2.22 m. (7.28 ft.) per month. In comparing these apparently very unsatisfactory results with the rate of advance and cost when sinking was being prosecuted with the aid of pumping, the case assumes an entirely different aspect. The portion of shaft from 92.3 to 101 m. (302 to 331.5 ft.), which occupied the time from October 9, 1896, to December 6, 1897, also took 14 months, while the total advance was only 9 m. (29.5 ft.), or an average monthly progress of 0.65 m. (2.13 ft.). The actual figures for cost for this part of the work may be stated as follows:

	Marks.
1. Three pumps, with a capacity of 34 cbm. (8976 galls.) per minute	165,000
2. Boiler-plant and buildings, complete	75,000
3. Piping, etc	5,000
4. Installation and dismantling of plant	40,000
5. Concreting shaft bottom	6,462
6. Wages, salaries, and small supplies	110,000
7. Sundry expenses	3,000
8. Fuel	46,000
Total	450,462
Less value of sale of machinery and boilers, 60% of purchase price	144,000
Net cost of 9 m. of shaft	306,462

Or about 34,050 marks per meter ($2595.00 per ft.).

It is but right to charge the concreting of the shaft bottom to this work. This would have been unnecessary, and time would have been saved if the management, on reaching the depth of 92.3 m. (302 ft.), had decided upon the immediate application of the Kind-Chaudron system. Besides the 300,-

000 marks expended in boring, the futile attempt to sink by hand-work and pumping, between the depths of 92.3 and 119.35 m. (302 to 390 ft.), cost, including the cuvelage to the 87.95 m. level, 306,462 marks; the grand total was 606,462 marks, or over 20,000 marks per meter (say, $1722.00 per ft.).

This statement again demonstrates, as has been shown elsewhere, that for very wet formations, and when good judgment is exercised in dealing with the conditions presented, the Kind-Chaudron is the safest, cheapest, and quickest method of sinking.

SINKING THE SHAFT OF THE POTASH-MINE, GEWERKSCHAFT ALEXANDERSHALL, AT BERKA ON THE WERRA. (PLATE XI.)

The conditions under which this shaft was sunk may be considered as unique. A heavy flow of water was encountered between the depths of 115 and 130 m. (377 to 426 ft.), under such pressure that from 3 to 4 cbm. (792 to 1056 galls.) per minute constantly flowed over the collar of the shaft during the progress of the work. This was anticipated, however, as the water spouted to a height of 10 m. (33 ft.) from the preliminary bore-holes, when they entered the dolomite at a depth of 115 m. (377 ft.) below the surface. Above that point there were no indications of any such flow of water. It was therefore evident that the formation above the dolomite could be sunk through by ordinary methods, but that the Kind-Chaudron system alone would serve for the lower portion of the shaft.

The shaft was begun early in June, 1899, some 40 m. (131 ft.) from bore-hole No. 2, on the high-road between Berka and Dippach. The formation was as follows:

Alluvium and diluvium	0 to 7.1 m.	(0– 23 ft.)
Lower Buntsandstein } Triassic	7.1 to 61.5 m.	(23–202 ft.)
Brittle shales. } Triassic	61.5 to 102.0 m.	(202–234 ft.)
Upper clay	102.0 to 114.98 m.	(334–377 ft.)
Stratified dolomite	114.98 to 130.0 m.	(377–426 ft.)
Red clay, with stringers of gypsum	130.0 to 161.5 m.	(426–529 ft.)
Anhydrite	161.5 to 162.5 m.	(529–533 ft.)
Upper Permian:		
Clay, with stringers of anhydrite	162.5 to 164.25 m.	(533–539 ft.)
Compact anhydrite	164.25 to 167.3 m.	(539–549 ft.)
Clay	167.3 to 169.8 m.	(549–557 ft.)
Compact anhydrite	169.8 to 181.0 m.	(557–593 ft)
Saliferous clay	181.0 to 191.0 m.	(593–625 ft.)
Rock-salt	below 191.0 m.	(625 ft.)

No difficulties in sinking were to be anticipated down to the brittle shales at 61.5 m. (202 ft.).

On July 24th the first wedging-crib was put in place at 20.45 m. (67 ft.). Ten tubbing-rings, 5.5 m. (18 ft.) in the clear and 1.5 m. (4.9 ft.) high, were built up from the crib, bolted together, and the spaces behind them concreted. The inflow of water, which had been 3.6 cbm. (950 galls.) per minute, was thus reduced to 1.1 cbm. (290 galls.). As sinking continued the flow again rose to 4.4 cbm. (1161 galls.), though this quantity was not continuously maintained. The Buntsandstein proved to be fissured, so that on blasting fresh accumulations of water were often encountered, increasing the flow temporarily until they had drained off. At 34.5 m. (113 ft.) an impervious stratum was cut, suitable for the setting of another wedging-crib, which was placed 35.8 m. (117 ft.) below the surface. Upon it tubbing was again built up, thereby reducing the inflow to 600 l. (158 galls.) per minute.

The work proceeded in a similar manner until a depth of 101 m. (331 ft.) was reached. At first the water was raised by Pulsometers; later a duplex pump was installed, and when this no longer sufficed a simple, direct-acting pump was added,

with steam-cylinder 1.4 m. (4.6 ft.) diameter by 3.15 m. (10.3 ft.) stroke, and two water-cylinders 0.5 m. (1.64 ft.) diameter, raising from 7 to 8 cbm. (1848 to 2112 galls.) per minute.

This method of sinking was discontinued May 8, 1900, at a depth of 101.33 m. (332 ft.), and preparations were made to continue by the Kind-Chaudron system. The preliminaries were completed by the middle of July, and boring began with a 2½-m. (8.2-ft.) trepan. On striking the dolomite, at 115 m. (377 ft.), the water, which had previously stood 5 m. (16.5 ft.) below the collar of the shaft, suddenly rose so that about 400 l. (105 galls.) per minute overflowed. As the small trepan advanced the flow increased to 3 or 4 cbm. (792 to 1056 galls.) per minute. The advance bore was continued to a depth of 133.6 m. (438 ft.), i.e., 2 m. (6.5 ft.) below the dolomite. By this time so much caving occurred between 100 and 115 m. (328 and 377 ft.) that it became advisable temporarily to line this portion of the shaft. Work with the large trepan (5.3 m. or 17.4 ft. diameter) was therefore begun and carried down to 111 m. (364 ft.), when it was stopped for putting in the lining. This was 5.23 m. (17.15 ft.) in the clear, 18 m. (59 ft.) high, and 30 mm. (1.17 in.) thick. When this cylinder reached the bottom of the shaft, work with the large trepan was resumed and the lining driven 2.83 m. (9.3 ft.) deeper, so that its lower edge rested at 114.13 m. (375 ft.). Sinking was continued to 115 m. (377 ft.) with the large trepan, slightly reduced in diameter so as to pass the lining. The advance bore was then deepened, reaching the 153-m. (502-ft.) mark on January 9, 1901, being at that point 23 m. (75 ft.) below the top of the red clay.

Falls of rock had been noticed for some time, so that it became imperative to line the shaft completely below the 115 m.

(377 ft.) point. While using the enlarging trepan the temporary lining had sunk 3 m. (10 ft.) farther, or to a depth of 118 m. (387 ft.), and when the enlargement had reached 139 m. (456 ft.), caving became so serious that additional lining was demanded at once. A second plate-iron cylinder 5 m. (16.4 ft.) inside diameter, 20 m. (65 ft.) high, and 15 mm. (0.58 in.) thick, was put in, after which the large trepan, correspondingly reduced in size, was again used. The lining then dropped down to 141 m. (461 ft.), where it remained pemanently fast. Below this point the rock became harder and showed no inclination to cave, so that the advance bore was terminated at 170 m. (557 ft.) and the full section shaft at 166 m. (544 ft.). There was 25 m. (82 ft.) of shaft below the second temporary lining, in which a satisfactory connection could be made between the cuvelage and the shaft walls.

The cuvelage was lowered between November 15 and December 18, 1901. It was 4.1 m. (13.44 ft.) in the clear and 82 m. (269 ft.) high. The operation of concreting between the shaft-walls and the cuvelage had to be done under unusual conditions, which had been the subject of much discussion as the work advanced. As the water overflowed at the surface, the shaft was filled with what was practically running water, which cannot be dammed back by fresh concrete. Experience and observation indicated that the chief source of this flow was in the dolomite and that the strata below were dry. In other words, although the water overflowed at the shaft mouth, it must necessarily be quiescent between the depths of 130 and 166 m. (426 and 544 ft.). It would be entirely practicable, therefore, to concrete the lower part of the shaft, and after making it water-tight the water could be shut out above by continuing the cuvelage to the surface.

As matters stood, the shaft was lined with tubbing for a depth of 97 m. (318 ft.) from the surface, so that under ordinary circumstances a cuvėlage reaching 15 m. (49 ft.) up into the tubbing would be amply sufficient. The management cast about for some means of making such an addition to the cuvelage as would meet the difficulty without large expense.

It happened that some 20 m. (65 ft.) from the shaft the ground was 2½ m. (8.2 ft.) lower than the shaft collar. This gave General Manager Naderhoff the idea of tapping the water in the dolomite by means of a bore-hole sunk at that point, which would naturally divert the flow from the shaft. Assistance in bringing about this result could be obtained by building up the masonry walling at the shaft mouth a few meters above the surface. Such a bore-hole was accordingly started and was completed before the shaft was down to its full depth; its diameter varied from 1 m. (39 ins.) at the mouth to 700 mm. (27 ins.) at the bottom. The outcome was only partially successful, much of the water still continuing to overflow at the shaft mouth, although a portion was diverted through the bore-hole. Nevertheless, the conditions for concreting were improved, as it became possible to cut out the upper flowing water at a lower point in the shaft.

The following method of concreting was adopted. The cuvelage from 130 to 166 m. (426 to 544 ft.) was concreted in the usual way, as the water was still. Then the spaces behind the portion of the cuvelage in the dolomite, between 115 and 130 m. (377 and 426 ft.), were filled with coarse gravel. This was intended to give the water access to the bore-hole, while at the same time presenting some obstruction to its rise through the inside of the shaft. Fine gravel and sand were afterward

filled in until the ascending current in the shaft ceased, when concreting in the usual manner was carried out, the work beginning on December 18th. By the middle of January the concreting had reached the 124-m. (407-ft.) mark. Then the upper masonry walling was raised 2 m. (6.5 ft.) more above the shaft collar; upon which the water-level rose to a point 1.84 m. (5 ft.) above the collar, where it came to equilibrium, the entire inflow of the shaft, barring a few small leakages, passing out through the bore-hole. Gravel was then filled in behind the cuvelage between 124 and 114 m. (406 and 374 ft.) depth, after which ordinary concrete filling was resorted to.

This work was finished February 1, 1902, and unwatering begun March 10, 1902. It soon became apparent that the results were satisfactory, only a few unimportant leaks appearing in the concrete, due to imperfections in laying it and to small rising currents of water during the progress of the work. These defects were easily remedied by the addition of two tubbing-rings, behind which concrete was tightly rammed.

The shaft was clear of water by March 27th, and sinking was resumed, preparatory to placing the bottom connecting tubbing-rings in position. This was done and the shaft completed about the middle of April, 1902.

Sinking the Shaft of the Potash-mine, Gewerkschaft Franz, at Lübtheen (Mecklenburg).

The Mecklenburg government, in the years 1874 to 1880, put down seven bore-holes in the immediate vicinity of a gypsum-quarry owned by the state. Four of these penetrated a rich potassium deposit, while two others were abandoned in rock-salt. In 1895 the government transferred its rights in

these deposits to a certain Sholto Douglas, who, at the end of the same year, started to sink a shaft near the edge of the gypsum. This location was chosen as the shaft would be almost wholly in the gypsum itself, which elsewhere was overlaid by sundry beds of sand and clay.

Bore-hole No. 1, which was close to the shaft, cut the following strata:

Yellow sand	0 to 7.3 m.	(0– 24 ft.)
White sand	7.3 to 11.8 m.	(24– 39 ft.)
Fine blue sand	11.8 to 17.5 m.	(39– 57 ft.)
Coarse sand	17.5 to 22.5 m.	(57– 74 ft.)
Gypsum, with sand and clay	22.5 to 31.5 m.	(74– 103 ft.)
Hard gypsum, with clay	31.5 to 37.5 m.	(103– 123 ft.)
Hard gypsum	37.5 to 59.8 m.	(123– 196 ft.)
Alternating gray and white gypsum	59.8 to 66.6 m.	(196– 218 ft.)
White gypsum	66.6 to 83.0 m.	(218– 272 ft.)
Alternating white and gray gypsum	83.0 to 95.2 m.	(272– 312 ft.)
White gypsum	95.2 to 135.2 m.	(312– 443 ft.)
Hard blue gypsum	135.2 to 174.0 m.	(443– 570 ft.)
White gypsum	174.0 to 179.5 m.	(570– 589 ft.)
Very hard bluish gypsum and anhydrite	179.5 to 200.0 m.	(589– 656 ft.)
White, crystallized gypsum	200.0 to 201.2 m.	(656– 661 ft.)
Soft white gypsum	201.2 to 209.0 m.	(661– 685 ft.)
Gray gypsum	209.0 to 284.0 m.	(685– 931 ft.)
Gypsum with stringers of rock-salt	284.0 to 288.0 m.	(931– 944 ft.)
Anhydrite and gypsum	288.0 to 315.0 m.	(944–1033 ft.)
Saliferous clay	315.0 to 327.0 m.	(1033–1072 ft.)

At the point where the shaft was begun the gypsum-quarry had been opened to a depth of 15 m. (49 ft.). The water was first removed from the quarry, and then masonry walling 5.6 m. (18.4 ft.) in diameter was built up from the bottom. Sinking was started by hand inside the walling, the water being raised by Pulsometers. The gypsum proved to be much fissured, with a large and troublesome inflow of water. At the end of 1896 the shaft was only 36 m. (118 ft.) deep and eight Pulsometers were no longer able to keep it free of water.

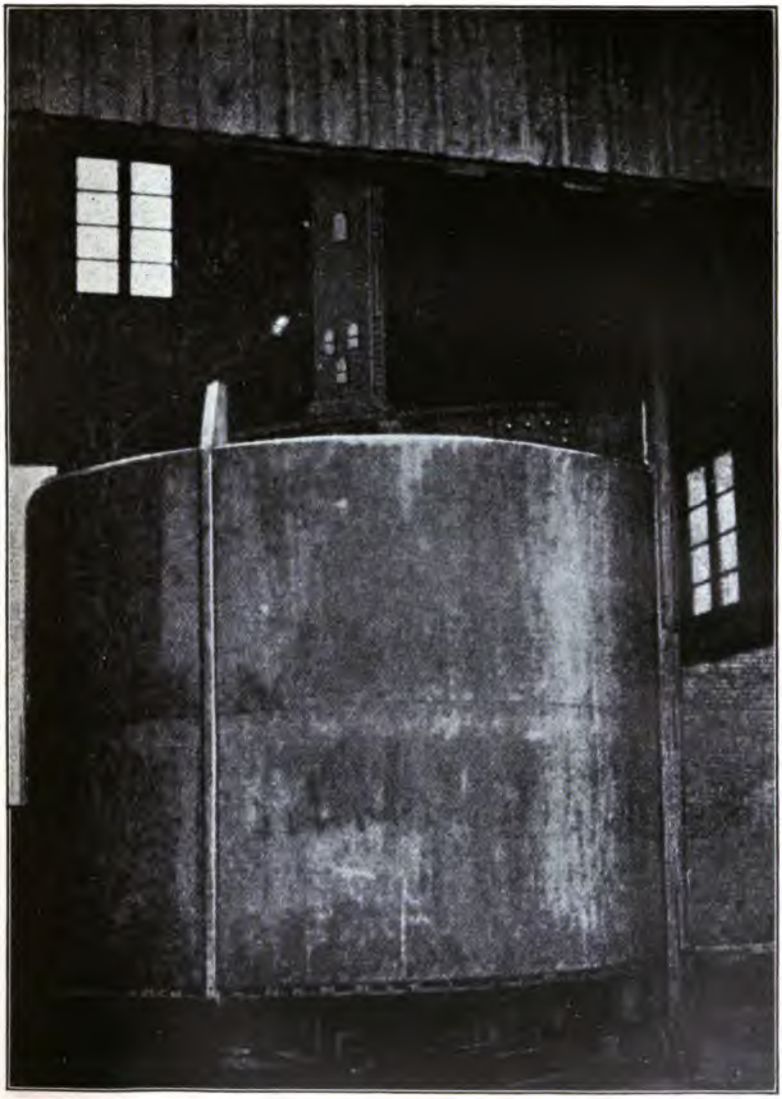

FIG. 5.—Gewerkschaft Friedrich Franz. Large Trepan with Guiding Cylinder and Lateral Bits on the Lower Edge.

As a result of this failure it was decided to install the Kind-Chaudron system. Preparations were completed by April 15th, and the small trepan was lowered for the first time on the 20th of that month, reaching a depth of 142 m. (466 ft.) by October 19th. The subsequent enlargement of the shaft to this depth with the large trepan was equally successful. But further advance was slower because of the steep dip of the strata and greater hardness of the rock. Serious difficulties were encountered between 180 and 205 m. (590 and 672 ft.) below the surface, where the strata were steeply inclined, and very hard in some places, though elsewhere varying from hard to soft, besides being much fissured. Broken bits frequently stuck in the fissures and could not be recovered by the grappling-tools. These pieces of steel remaining in the bottom were a further source of trouble, and retarded the daily advance. A frequent tendency of the trepans to diverge from the vertical also became noticeable, so that the shaft walls had frequently to be dressed down. The work was not only difficult but met with manifold mishaps.

On May 16, 1899, the advance bore was at 203 m. (666 ft.) depth and the enlargement at 179 m. (587 ft.). At this point the boring-rod broke directly above the small trepan. All attempts to pick up and raise the trepan failed; the broken end of the rod was probably jammed in some fissure in the walls so that it could not be grappled. After several months of fruitless efforts it was decided to abandon the advance bore temporarily, to continue with the large trepan to where the small one was stuck, and then to drill around the latter. The small trepan was first covered with a layer of sand in order to avoid embedding it immovably in slimes. The enlargement of the shaft was very difficult in the steepy dripping broken ground,

varying as it did in hardness, and was not concluded until April, 1899. Every attempt made to drill around the small trepan failed because of the hardness of the rock. The long boring-rods vibrated so that it was feared they might break off.

Finally it was decided to break up the lost trepan. This was successfully accomplished after about four months' work, and the obstructing-tool was brought to the surface in fragments of varying size. Work advanced regularly after this, and on November 13, 1899, a depth of 242 m. (794 ft.) was attained, at which point the moss-box of the cuvelage was to be put in position.

A test of the shaft made by means of a wooden template showed that there were various irregularities in the walls requiring rectification. This work could not be done with the large trepan even after lengthening its guides to 7 m. (23 ft.), because the bits could not be made to cut at the points where the inequalities were found. Previously, success had always accompanied the use of such apparatus, even at Jessenitz. The trepan was eventually provided with a cylindrical mantel 3.5 m. (11.5 ft.) high (Fig. 5) around the lower edge of which small bits were set. The adoption of this device was based on the assumption that where there was a protuberance on one side of the shaft there was bound to be a corresponding depression on the other side. The results proved this theory to be correct.

By the early part of March, 1902, the work had proceeded until the few remaining inequalities in the shaft walls were not deemed of enough importance to prevent the lowering of the cuvelage. The event, however, showed this to be an error, for the cuvelage stuck fast at 143 m. (469 ft.) and could be lowered no farther, so that on March 23, 1902, it was decided

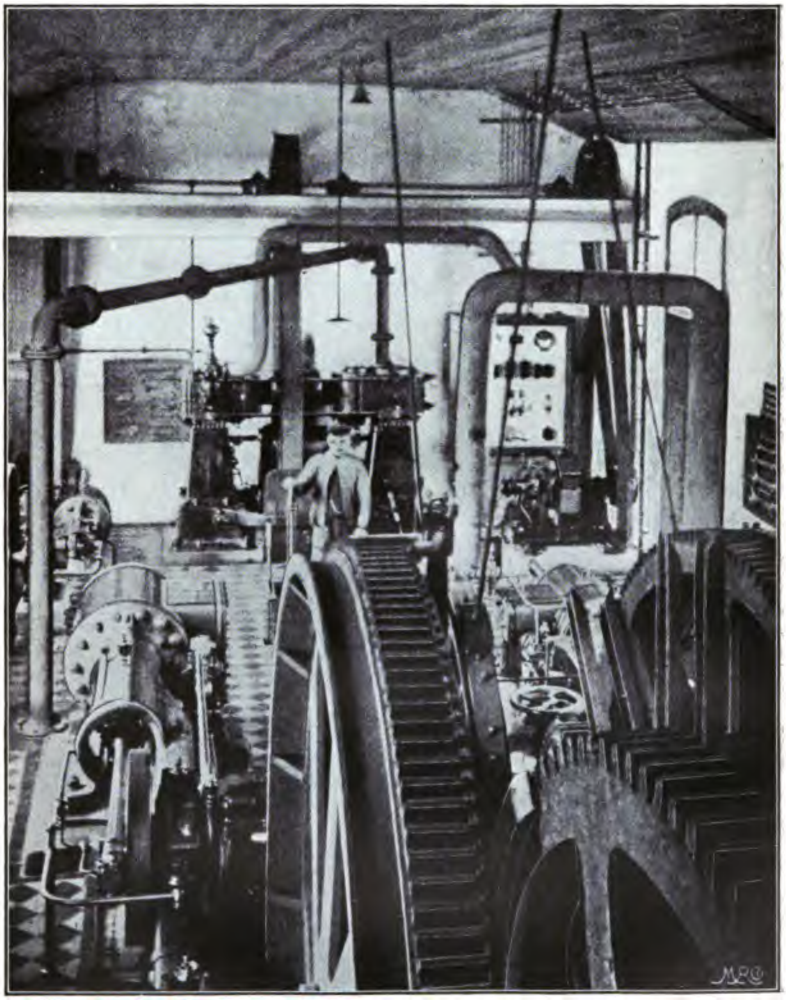

Fig. 6.—Boring-engine at the Works of the Gewerkschaft Friedrich Franz.

to raise it again, reduce the diameter of the moss-box rings, and again dress down the shaft-walls. (Figs. 6 and 7 show sundry details connected with the drill-work and the lowering of the cuvelage, which are self-explanatory.)

During the summer of 1902 the cuvelage was finally installed and the concreting completed, but on pumping out the shaft it was found that some small quantity of water leaked through the moss-box. On removing the cover and lower diaphragm of the cuvelage and reaching the sump, the water was found to come chiefly from small fissures and crevices in the rock; but little entered through the moss-box, which was practically water-tight, save at the points where the above-mentioned crevices ran under it.

As the water increased rapidly on beginning sinking by hand, work had to be discontinued, the shaft was allowed to fill again and boring resumed. Since the cuvelage was only 3.65 m. (11.87 ft.) in the clear, the trepan was reduced to 3.6 m. (11.8 ft.) in diameter, for boring the full area at one operation, rather than beginning with an advance bore, which would not have paid. By the end of May, 1904, a point was reached at a depth of 285 m. (935 ft.), where it was believed that the water could be successfully excluded. After the usual preparations, a new cuvelage 3 m. (9.84 ft.) inside diameter was installed during June, and concreting was finished early in July, 1904.

The second unwatering of the shaft began in August. It soon became evident that the cuvelage was not water-tight. Although its top could be almost uncovered by constant bailing with two water-skips, it could not be laid entirely bare so as to permit its removal. As the flow increased too much to be held back by the pumping facilities available, the space below the bottom diaphragm was filled with concrete, as well as a

portion of the equilibrium-pipe. After this concrete had set, pumping was resumed; but it was clear that the inflow had not ceased, and must therefore come from the upper part of the cuvelage—a fact which had been suspected for some time. It was then decided to place nine additional rings, each 1.5 m. (4.9 ft.) high and in sets of three, on the top of the cuvelage. Each set of three rings was provided with guides, so that it could be accurately centered. The lowest set was provided with a shoe and lead gasket to fit on the top of the main cuvelage, and each of the two following sets had lead and rubber gaskets so as to make tight joints. These rings were successfully lowered by means of hooks and rods. The space between them and the original cuvelage was then concreted, and after sufficient time had elapsed the shaft was again unwatered, this time with entire success.

Sinking of the "Georg" Potash Shaft of the "Gewerkschaft Grossherzog von Sachsen".

This company owns ground adjoining the Kaiseroda and Bernhardshall properties. On January 12, 1898, a shaft was begun at Dietlas.

The experiences of the neighboring mines indicated the probability of heavy inflows of water during the work, and large pumps were therefore installed, together with arrangements for boring the shaft, should it become necessary.

The first water was encountered at 5 m. (16 ft.). The flow increased so that at 100 m. (328 ft.) it amounted to from 1.5 to 2 cbm. (396 to 528 galls.) per minute, and between 117 and 122 m. (384 and 400 ft.) to 7 cbm. (1648 galls.) per minute.

Fig. 7.—Gewerkschaft Friedrich Franz. Tubbing-ring Standing Over Shaft ready to be Lowered.

It came from small crevices, which cut the Buntsandstein at an angle of about 70°.

The shaft, 5.25 m. (17.2 ft.) in diameter, was lined from the surface down to 266 m. (872 ft.) with tubbing of the usual design, having machined flanges and lead packing, all furnished by Haniel & Lueg. At 190 m. (623 ft.) the main flow of water was practically cut off, but the tubbing was carried down to the full depth of 190 m., partly because a little water still entered, and also because the character of the ground made it desirable. Below 266 m. (872 ft.) the shaft was entirely dry, and from that point to the 340 m. (1115 ft.) level was lined with masonry 5.6 m. (18.4 ft.) inside diameter. At the last-named depth a diamond-drill hole put down to investigate the water-bearing strata showed that the dolomite formation was very wet, as was to be anticipated in the light of the experiences of neighboring mines. This decided the management to stop sinking by hand and to prosecute the work by the Kind-Chaudron system, the contract being given to Messrs. Haniel & Lueg.

The shaft having been cleaned out, a pit 2.5 m. (8.2 ft.) in diameter was sunk in the bottom as a guide for the advance trepan. After completing the requisite surface equipment, boring was started March 21, 1901, with the small trepan. In the brittle shales first encountered, the work advanced rapidly, and the dolomite was reached in June, 1901, at a depth of 369.64 m. (1212 ft.). At first good progress was made in the dolomite, but it soon became harder and more fissured, occasioning breakages of bits and consequent delays. The dolomite was passed through by August 7, 1901, at a depth of 387.90 m. (1272 ft.), the shaft then entering blue clays and red marls, the latter full of anhydrite stringers.

Judging from the character of the formation, the management hoped to find a suitable bed for placing the moss-box at a depth of 400 to 410 m. (1312 to 1345 ft.). Drilling with the small trepan was therefore stopped October 20, 1901, at 412.30 m. (1352 ft.). This work thus far had been uneventful, with the exception of some minor breakages of bits and rods. Moreover, but little rock had fallen from the walls of the shaft, most of it coming from the horizon of the brittle shales, which were found to be harder here than at Kaiseroda.

Work with the large trepan, 4.96 m. (16.27 ft.) diameter, was begun on October 25, 1901, and progressed without difficulty until the dolomite was reached. Then breakages of the bits and caving of the shales became so frequent that it was decided to line the 12 m. (39 ft.) of shaft immediately above the dolomite. A plate-iron casing, weighing 37,000 kg. (81,400 lbs.), was lowered by rods and hooks, and ultimately suspended in the usual manner by four flat ropes.

Boring was then resumed, and after numerous minor difficulties, due to the character of the rock, the dolomite was passed through in the latter part of September, 1902. One break in the drill-rods, which allowed thirteen lengths of rod to fall and jam in the shaft, caused six weeks' delay. After this, however, boring advanced with ease to a depth of 404.2 m. (1325 ft.), where it was finally stopped, March 15, 1903. Additional sections of casing, 13.5 m. (44 ft.) in height, were put in place above those first installed, in order to avoid all possibility of ground caving from the brittle shales, this work being completed March 25, 1903. The shaft was then carefully cleaned of all debris by means of the sludger. This was the more important, because during the drilling operations it had been repeatedly observed that much fine mud and sand came

in from the shaly strata, which it was feared might endanger the success of the proposed concreting.

The work of assembling the moss-box and accompanying rings commenced April 15th, and the lowering of the cuvelage was begun in the night of May 7th to 8th. When the lower end reached the 284-m. (931-ft.) mark, a sudden increase in weight occurred, so that the threaded lowering-rods broke, allowing the entire cuvelage to drop about 120 m. (393 ft.). But the relation of the weight and displacement of the cuvelage was such that it settled slowly and came to rest on the bottom without shock; no damage was done, the cuvelage remaining intact in shape and perfectly water-tight. Although the increase in weight must have been caused by the influx of water, it was ultimately found that the false bottom, cover, and equilibrium-pipe were all in good condition. The occurrence can be explained only on the supposition that something must have happened to the inlet-valves of the equilibrium-pipe, although they also were found to be in proper order. When the cuvelage had settled into place, the accuracy of its position in the shaft was first determined, after which the work of concreting was begun. Unfortunately, the partial, temporary lining of the shaft was neither perfectly plumb nor round, as had been evidenced by the rubbing of the large trepan and its guides, so that the concreting, the most important operation in the water-proofing of the shaft, could be carried on with only two buckets. Aside from this no events of importance were chronicled.

Six weeks later, on July 14th, the work of unwatering was begun. At 136 m. (446 ft.) the inflow exceeded the pumping capacity, being 1.3 cbm. (343 galls.) per minute. It was supposed to come from below the moss-box and to ascend through the equilibrium-pipe. The water was very muddy and in-

creased to 1.45 cbm. (382 galls.) per minute, so that unwatering had to be discontinued July 17th.

An attempt was then made to concrete the space below the false bottom and the lower portion of the equilibrium-pipe by running liquid cement down through an inner pipe inserted in the equilibrium-pipe. This work was completed on August 31st, in 1½ days, 35,000 kg. (77,000 lbs.) of cement having been used. Four weeks later the shaft was unwatered without difficulty down to the cover of the cuvelage, which was then removed and hoisted to the surface on October 11, 1903. Unwatering was continued to the bottom and proved conclusively that the cuvelage was practically water-tight, only a few liters of water leaking into the shaft at places where the wire ropes which supported the temporary outside lining-rings protruded through the concrete walls. This leakage was obviated afterward by putting in a few more sections of cuvelage and concreting them above the older section.

A valve was then attached to the steel bottom of the cuvelage and the bottom drilled through inside the valve. A flow of 80 l. (21 galls.) of water per minute was found, at a pressure of 41 atmospheres, carrying much mud and some carbonic-acid gas. This proved that the concreting had been defective, and, as it would have been a difficult matter to remove the false bottom of the cuvelage with such a flow of water, particularly as an increase was to be anticipated, it was finally decided to try to make this part of the shaft water-tight by introducing cement as before. For this purpose the cuvelage was drilled through at a number of points and considerable water drawn off. As a rule the water was very muddy, and at some of the openings thick mud was forced out. Usually the material consisted simply of clay, in some cases of argillaceous lime of

impalpable texture, again of clay and cement mixed. Large amounts of it were thus tapped off, besides what was carried in the water itself and what had been found originally on the cover of the cuvelage.

As everything possible had been done to clear the shaft of debris before the cuvelage was lowered, it was plain that these new accessions of mud must have been either in suspension or dissolved in the water as carbonates. The concreting had of course introduced a certain amount of heavy slimes, which carried down mechanically a part of the suspended matter; and the lime in the cement probably caused a chemical precipitation of a portion of the carbonates by taking from them carbonic acid. Thus only can the presence of such considerable amounts of fine slimes be explained. The quantity of this material may be estimated from the fact that on drilling through the cuvelage-walls it appeared that in the lower horizon, where the cement-buckets had passed, two solid columns of concrete had been formed, and consequently no water was tapped through these holes. But in the space between these two columns and over the entire remainder of the circumference mud and water were very much in evidence. The drainage-ditches on the surface which carried the water off to the Felda were so filled with mud that the river itself was polluted. It is quite evident that these conditions prevented the concreting from completely fulfilling its purpose.

We have now to return to the mode of introducing liquid cement. After allowing the mud and water to run from the various tap-holes until the inflow was quite clear, liquid cement was forced from the surface, through a 30-mm. (1.17-in.) pipe, into the spaces behind the cuvelage until no more would enter. The plan followed was to seek out the accumulations of mud

behind the lower part of the cuvelage, clear them out and flush in cement to replace the mud. This work was completed November 23, 1903, after some 40,000 kg. (88,000 lbs.) of cement had been introduced. When the cement had set the false bottom was removed, and that the operations had been entirely successful was shown by the fact that only some 2 l. (½ gall.) per minute leaked into the shaft from beneath the moss-box. The false bottom was raised to the surface December 30th, and the work of rendering the shaft water-tight finished about the middle of January, 1904, by the successful installation of the connecting tubbing-rings, down to the coal underlying the dolomite.

The work at this shaft was particularly interesting, as it is the deepest thus far sunk by these means, the lower edge of the connecting tubbing being 407 m. (1335 ft.) below the surface. It demonstrated, also, that the method can be successfully applied even under such adverse circumstances as were brought about by the accumulation of mud, since the flushing in of cement affords a satisfactory means of remedying any defect in the original concreting.

Shaft-sinking at the Ronnenberg Potash-mines, in Hanover.

In the third part of this work the sinking of the Ronnenberg shaft by the freezing process is described in detail. The process had to be abandoned, however, after the hard gypsum had been reached, at a depth of 125 m. (410 ft.), because of a sudden inflow of water. As at Benthe-Wallmont, the application of the boring system was rendered difficult, because the lower part of the shaft, from 105.4 (346 ft.) to 125 m. (410 ft.),

was only temporarily lined. It became necessary, therefore, to keep the freezing-plant going for some time, and to guard against rock falls in this part of the shaft by a provisional plate-iron lining. Much time and money might have been saved if the tubbing had been suspended from the wedging-crib above and had been kept up close to the work as it advanced. The advantages accruing from suspending the tubbing have been presented clearly in the first part of this essay, in describing the work at the Zollern and Emscher-Lippe shafts. The author has for years advocated this plan, in connection with the Poetsch as well as other methods of sinking, but thus far without result.

In the case under consideration the water broke through at a depth of 125 m. (410 ft.) on November 29, 1901. By the middle of December the bottom of the shaft had been concreted to a depth of 8 m. (26 ft.) and then filled with gravel to the 111.5-m. (365-ft.) point. After testing the shaft with a template, more gravel was filled in to 104.5 m. (342 ft.) below the collar, and a vigorous attempt made, between January 21st and March 8, 1902, to check the inflow of water by freezing. Unwatering was then successfully accomplished down to the top of the gravel, but on March 24, 1902, another inrush occurred, flooding anew the entire shaft.

The freezing process was now definitely abandoned and preparations were begun for boring. The work of securing the lower part of the shaft, which as yet had had no permanent lining, was started July 29, 1902, by putting in a plate-iron casing. By November 11, 1902, the concrete in the sump was bored through, and a second casing was installed between November 12 and December 9, 1902.

Boring was begun December 10th. The casing referred to

above was allowed to follow the trepan down, undercutting of the shaft walls being frequently necessary to facilitate its descent. The work, which was interrupted but little and that only by minor breakages of the trepans and rods, was stopped on July 8, 1903, in order to put in a third plate-casing. The advance trepan was then at a depth of 156 m. (511 ft.) and the full section at 151 m. (495 ft.).

In the latter part of July, a diamond-drill hole was started in the shaft-bottom to ascertain the character of the underlying formation and the quantity of water to be expected. This prospecting, which was satisfactorily finished by the latter part of September, indicated that the best place for the moss-box of the cuvelage would be at 185 m. (607 ft.) below the collar of the shaft.

Boring operations were then resumed and proceeded with, there being no more serious delays than those caused by broken trepans and rods. In one case, when the large trepan had broken from the rod, it dropped 30 m. (98 ft.) after having been successfully grappled, and while being hoisted to the surface.

On January 22, 1904, the advance bore was stopped at 193 m. (633 ft.), and on February 16th the enlargement was finished at 183.68 m. (602 ft.). After the requisite preliminaries the cuvelage was begun February 26th and successfully completed on March 24th. Concreting the cuvelage occupied the time from March 30 to April 23, 1904, the lower part of the concrete being made of magnesia cement and the upper of Portland, according to whether the shaft-walls were in rock-salt or not. Unwatering the shaft was begun early in June, and the cuvelage was found to be perfectly water-tight; so that the connecting tubbing below the moss-box was promptly installed and the shaft turned over to the Ronnenberg Company.

Shaft-boring and Lining with Cuvelage at Great Depths.

Of late years several shafts have been sunk to depths of 600 m. (1968 ft.) or more, and it seems unquestionable that cases will arise in which sinking by boring will have to be resorted to even for such great depths as these.

The thickness of a cast-iron lining 4.4 m. (14.4 ft.) in diameter, for a depth of only 400 m. (1312 ft.) and allowing for a crushing strain of 800 kg. per square centimeter (about 11,350 lbs. per square inch) would be 110 mm. This is a very great thickness, and in fact 110 to 125 mm. (4.29 to 4.87 ins.) is at present the maximum thickness obtainable with safety under present methods of manufacture, aside from the fact that such rings are so heavy as to render their transportation a matter of much difficulty. The allowance of a greater breaking strength than 800 kg. per square centimeter is scarcely safe, and no advantages accrue from the use of cast steel, as it and cast iron have about the same ultimate crushing strength. For greater depths, therefore, it becomes necessary to reduce the diameter of the cuvelage if the rings are to be of reasonable thickness. But any great reduction is impossible, because, beyond a certain minimum cross-section, the shaft would be too small for the necessary hoisting and pumping equipment, for airways and the transportation of men and material.

Tomson, the general manager at Dahlbusch, near Gelsenkirchen, suggested * for the two shafts of "Georg-Marien Hutte" at Werne, which were each 580 m. (1902 ft.) deep,

* Article by Bergassessor L. Hoffmann, *Gluckauf*, April 27, 1901.

that in case boring became necessary a diameter of 5.8 m. (19 ft.) should be adopted, and that in this cross-section two cuvelages each of 2.5 m. (8.2 ft.) inside diameter and two of 1.65 m. (5.4 ft.) diameter be placed, the spaces between them being concreted. It was intended that the larger compartments be used for hoisting, the smaller to serve respectively for pumping and handling of men and material. The walls of the 2.5-m. (8.2-ft.) compartments (measuring 2.9 m. or 965 ft. over all) at 580 m. (1902 ft.) depth would be $\frac{145.58}{800}=105$ mm. (4.1 ins.) thick, or quite within feasible limits. This proposal of Tomson's (under German patent No. 99,687) was not tried at Werne, however, as boring proved unnecessary and sinking was completed by hand to the coal-measures.

Instead of diminishing the diameter of the cuvelage until its thickness becomes practicable, the author has suggested the use of two concentric linings, the annular space between the two being filled with compressed air, water under pressure, or concrete. Assuming that each cylinder will safely withstand an outside pressure of 30 atmospheres, and that the space between them be filled with air at this pressure, they would serve for a depth of 600 m. (1968 ft.). Aside from the facility with which these rings could be cast, the use of two concentric cylinders would reduce the difficulties of lowering them, as the weights to be handled would be far less than for a single cylinder, designed for the same depth and diameter. As an example may be cited the case of a shaft 600 m. (1968 ft.) deep, with a cuvelage 4.1 m. (13.4 ft.) clear diameter and rings 1.2 m. (3.9 ft.) high. The lower rings would have to be 180 mm. (7 ins.) thick, each weighing 30,000 kg. (66,000 lbs.), and the weight

of the moss-box alone would be nearly 100,000 kg. (220,000 lbs.).

The process of lowering the cuvelage is as follows: Upon a scaffolding erected above the water-level in the shaft the moss-box and false bottom are put together. The first ring is then bolted to it and the lowering-rods attached, from which the moss-box and ring are suspended. The scaffolding is removed and the cuvelage lowered so that about 0.5 m. (1.6 ft.) still stands above the surface of the water. In this position 28,000 kg. (61,000 lbs.) of water will be displaced, so that only some $(100,000+30,000)-28,000=102,000$ kg. (224,400 lbs.) remain suspended from the rods. The displacement due to a ring 4.1 m. (13.4 ft.) diameter and 1.2 m. (3.9 ft.) high is 18,000 kg. (39,600 lbs.), and as such a ring weighs 30,000 kg. (66,000 lbs.), each additional ring will increase the strain on the rods by $30,000-18,000=12,000$ kg. (26,400 lbs.). Although the weight will of course be somewhat reduced by diminishing the thickness of the upper rings, it is readily seen that the weight of such a cuvelage would soon become too great to be supported by a set of lowering-rods of any reasonable size.

By adopting double cuvelages the individual rings will be but half as thick, and consequently only one half as heavy. In this case the moss-box, false bottom, and outside rings are first lowered. The weight of water displaced by each ring is as before 18,000 kg. (39,600 lbs.), and the weight per ring being only 15,000 kg. (33,000 lbs.) each additional one put in place and lowered reduces the strain on the rods by $18,000-15,000=3000$ kg. (6600 lbs.). This reduction in weight increases as the upper rings with their smaller thickness are lowered, so that the rods are soon relieved of all strain and the cuvelage floats in the shaft.

In deep shafts it thus becomes possible that the excess of buoyancy, which heretofore has always been overcome by admitting water inside the cuvelage, will suffice to support the weight of the second or inner cylinder. Therefore the installation of the latter may be commenced at the moss-box, and continued upward coincidently with the erection of the outside rings, as the increase in buoyancy may permit. After the inner cuvelage has reached the requisite depth, its top is closed and the space between it and the outer cuvelage temporarily filled with air compressed to such degree as may be rendered necessary by the external pressure on the lining. The outer cuvelage may then be carried to its full height and lowered into place without risk. Finally the compressed air is replaced by water and the space between the walls of the shaft and the outer cuvelage may be concreted. When the shaft is completed the water in the annular space between the cuvelages must stand sufficiently high to relieve the outer cylinder of undue pressure, unless concreting of this space be preferred.

Naturally, for unusually deep shafts, the cuvelage under these circumstances will be very high and may considerably exceed the length really necessary for rendering the shaft water-tight. In such cases the outside cuvelage will be concreted only as far as may be necessary, and the superfluous rings removed.

When only a short double cuvelage is required in a deep shaft, the following method is advantageous: For sinking the outside cuvelage, provided with false bottom and top, the usual method is employed, except that the cylinder is filled with compressed air. This may be done by means of a pipe-line attached to one of the lowering-rods, the pressure being increased as depth is attained so that it constantly corresponds to one half

of the outside pressure. When the cuvelage reaches the bottom the air is replaced with water and the outer space concreted as usual. The cover of the cuvelage, which is so designed that it can be removed under water, is then raised to the surface and the equilibrium-pipe taken out. The bottom is then either bored through, and the inner cylinder, similarly equipped with false bottom and top and filled with compressed air, lowered into place, or else the bottom is left intact and the inner cuvelage lowered upon it.

The best method of placing such cuvelages depends largely on their length, and is a question to be decided in each case. It may be remarked incidentally that these methods were designed by the author, and are patented in Germany under No. 125,789, by Haniel & Lueg.

Cuvelages of Sectionalized Rings, Lowered Without the Aid of Buoyancy.

The author has recently revived the idea of using sectionalized rings for lining shafts. The assistance of buoyancy in lowering the cuvelage is then no longer available, as it is impracticable while sinking to calk the joints sufficiently well to be sure of excluding all water. But, when feasible, many advantages can be secured by adopting this plan. In the first place, the diameter of shafts could be increased beyond the present 4.1 m. (13.4 ft.), as limited by questions of railway transportation. Secondly, shafts of any diameter and depth could be sunk by boring, as it would be possible to start with any desired size and to place within one another such a number of cuvelages as would withstand whatever pressure might be

involved. The method of procedure, patent for which has been applied for by the author, is explained below.

To carry out this plan, in accordance with which the rings must be lowered under water singly or in sets of reasonable size, and then bolted together, two problems must be solved.

The first and most important point is that the lowest rings shall be placed exactly concentrically in the bottom of the shaft, and that their flanges be exactly horizontal. They can be centered by means of vertical guides firmly fixed to the shaft-walls. But their horizontality cannot be assured by allowing them simply to rest on the bottom of the shaft, as that is neither necessarily horizontal nor always free from sand or pieces of fallen rock, the presence of either of which would tilt the rings and deflect the cuvelage from the vertical so that it would come in contact with the walls of the shaft. The author consequently proposes that the lowermost section of cuvelage be first suspended near the bottom of the shaft in an exactly vertical position, by a special yoke and hook attached to the boring-rods, and that when all oscillation has ceased concrete be filled in around the rings, thus holding them firmly in position. After removing the lowering-hook, the next set of rings is lowered and put in place, and so on. The coincidence of the axes of the successive sections is readily secured by the vertical guides already mentioned. Of course the horizontal flanges cannot be bolted together under water. This work is postponed until the shaft is being unwatered. A suspended scaffold is lowered, from which each flange-joint is bolted and calked as it appears above water.

The second problem is the temporary calking of the horizontal joints of the sections while the cuvelage is being built up under water. This is accomplished by placing a lead packing-

ring between the flanges, which in the final work can be driven home and rendered perfectly water-tight. The lead is supplemented by a packing of some more elastic material, which will last during the period of construction and be rendered water-tight by the weight of the rings and pressure of the water. The best kind of supplementary packing is a rubber ring lying in a groove of triangular section. A more minute description of the various details necessary to insure the success of this procedure may be omitted here, and it may be assumed that the cuvelage has been completed to the desired height. As the moss-box and false bottom and top are unnecessary, concreting in the usual manner would follow immediately.

After the concrete has set the shaft is pumped out, and at the same time the horizontal flanges calked permanently and bolted together. The rings as furnished by the iron-works are provided with bolt-holes on one flange only, as it would be impossible to place the rings in the shaft with sufficient accuracy to bring the bolt-holes exactly over each other. The holes in the other flange are made by electric drills operated from the suspended platform.

In the absence of false bottom and top there is nothing to prevent immediate resumption of sinking on completion of the cuvelage. And as there is no moss-box, the customary connecting-tubbing rings would usually be considered superfluous, although to insure success in excluding the water they are still frequently used. In employing this method, it is immaterial whether the cuvelage extends to the shaft-collar or ends under water. If necessary for shafts of great depth it is entirely feasible to put one cuvelage inside another, according to the author's patent, No. 125,789, as already described. The outer cuvelage is first installed and concreted; the inner is then

lowered and the space between the two filled with water or concrete.

As soon as this method shall have been satisfactorily tested it will undoubtedly greatly extend the use of the Kind-Chaudron system of sinking, as the sizes of shafts will no longer be limited to the relatively small diameters which hitherto have been great drawbacks to the adoption of the boring system. For very deep shafts in wet ground the improvements covered by the above-mentioned patent are of the greatest importance, because boring is alone applicable below a certain depth, the freezing method being out of the question, for certain reasons to be discussed hereafter.

Improvements have progressed rapidly in the various lines referred to, and the numerous difficulties encountered in each case have always been successfully overcome. The subjoined list of shafts sunk by the Kind-Chaudron method shows not only that it has frequently been used, but also that it has always been successful, even under the most trying conditions. It is worthy of note also that boring has usually been applied only as a last resort, for which reason but a relatively small portion of each shaft has been sunk by this system, and that this particular portion has been almost invariably that in which the maximum difficulty was encountered. For these reasons, in comparison with other systems of sinking, the boring method often appears in a very unfavorable light as regards speed of advance and cost. But it is manifestly unfair, as regards cost, to compare a method which leads to success, even under the most adverse circumstances, with others which have failed under the same conditions. It would be equally just to make comparisons between speed and cost of two shafts put down

by hand, one with, say, 10 cbm. (2640 galls.) of water per minute and the other entirely dry.

In many cases, when it is foreseen that a part of the shaft will have to be bored, it would be better to start with the Kind-Chaudron system before the obstacles to sinking by hand become insuperable. The work of boring would then begin, at least, under fair conditions; it would progress rapidly, giving a good average advance, and allow of distributing the large initial expense of plant, etc., over a greater depth of shaft. Such a policy would reduce the expenditure—usually very large—which, as a rule, is wasted in trying by other means to force a way through the last difficult strata before finally resorting to boring. It would probably be found in the end that a larger part of the shaft could have been more cheaply and quickly completed by boring than by the means actually employed, simply because sinking operations in very wet ground are slow and costly when conducted by ordinary methods, whereas after the boring-plant is once installed, the actual running expenses are very moderate.

TABLE No. 1.—LIST OF SHAFTS SUNK BY THE KIND-CHAUDRON SYSTEM TO 1904.

No.	Country.	Place.	Name of Company.	No. of Shafts	Diam. of Shaft.	When Sunk. Begun	When Sunk. Completed.	Depth of Shaft.	Thickness of Loose Ground Requiring Temporary Lining.	Remarks.
					Meters			Meters	Meters	
1	Germany	Rotthausen	Bergwerks-Gesellschaft Dahlbuch, Shaft No. 1........	1	3.50	1852	1854	117		
2	Belgium	Peronnes	Cie. des Mines de Peronnes, St. Waast shaft..........	1	3.65	1854	1856	98		
3			Ditto....................	1	1.83	1859	1860	105.2		
4			Ditto....................	1	3.65	1862	1863	86.6	8	Cased provisionally through sand between 75 and 83 m.
5	Lorraine	Spittel	Saar- u. Mosel-Bergwerks-Ges., Shaft No. 1.........	1	1.83	1863	1865	158		Air-shaft
6			Ditto, Shaft No. 2.........	1	3.35	1864	1866	159		
7	Germany	Rotthausen	Bergwerks-Ges. Dahlbusch..	1	1.9	1865	1867	101		Air-shaft
8			Ditto, Shaft No. 2..........	1	3.65	1866	1868	104		
9	France	Dorignies	Cie. des Mines de l'Escarpelle, Shaft No. 4.............	1	3.2	1868	1869	104		These two shafts sunk 22 m. by hand; then lined with wooden cuvelage, but abandoned because of excessive inflow of water
10			Ditto, Shaft No. 4 *b*........	1	2.14	1869	1870	104		
11	Belgium	Maurage	Cie. des Mines de Maurage...	1	3.65	1869	1872	190		
12			Ditto....................	1	4.00	1869	1872	190		
13		Peronnes.	Cie. des Mines de Peronnes, St. Waast shaft	1	3.65	1872	1873	72		

NOTE.—One meter = 3.28087 ft.

TABLE NO. 1.—LIST OF SHAFTS SUNK BY THE KIND-CHAUDRON SYSTEM TO 1904—*Continued.*

No.	Country.	Place.	Name of Company.	No. of Shafts	Diam. of Shaft.	When Sunk.		Depth of Shaft.	Thickness of Loose Ground Requiring Temporary Lining.	Remarks.
						Begun	Completed			
					Meters			Meters	Meters	
14	France	Liévin	Cie. des Mines de Liévin	1	3.65	1872	1873	89.5		
15		Meurchin	Cie. des Mines de Meurchin	1	3.20	1872	1873	84.6	32	Sunk by hand and lined with wooden cuvelage for a depth of 32 m.
16		Douchy	Cie. des Mines de Douchy	1	3.65	1872	1873	37.6	20.1	Cased provisionally in quicksand and gravel for 20 m.
17	Germany	Rotthausen	Bergwerks-Ges. Dahlbusch, Shaft No. 3	1	3.65	1873	1874	88		
18	France	Liévin	Cie. des Mines de Liévin	1	3.65	1873	1874	80.2		
19		Meurchin	Cie. des Mines de Meurchin	1	3.20	1873	1875	89	31	Cased provisionally to depth of 31 m.
20		Annezin	Cie. des Mines de Wendin	1	3.65	1873	1875	111.3	28	Ditto to 28 m.
21		Auchel	Cie. des Mines de Marles, Shaft No. 3	1	3.65	1873	1874	115	6.1	Cased in the blue marls between 83.3 and 89.4 m.
22	Belgium	Giply	Cie. des Mines du Midi de Mons	1	3.65	1873	1874	85.1	11	
23	Germany	Rotthausen	Bergwerks-Ges. Dahlbusch, Shaft No. 4.	1	3.65	1874	1875	88		
24		Spittel	Saar- und Mosel-Bergwerks-Ges., Shaft No. 3	1	2.14	1874	1876	170		Air-shaft
25			Ditto, Shaft No. 4.	1	3.65	1874	1876	175		
26	Belgium	Giply	Cie. des Mines du Midi de Mons	1	3.65	1874	1875	89.5	11	

NOTE.—One meter = 3.28087 ft.

TABLE NO. 1.—LIST OF SHAFTS SUNK BY THE KIND-CHAUDRON SYSTEM TO 1904—*Continued.*

No.	Country.	Place.	Name of Company.	No. of Shafts.	Diam. of Shaft.	When Sunk. Begun	When Sunk. Completed.	Depth of Shaft.	Thickness of Loose Ground Requiring Temporary Lining.	Remarks.
					Meters			Meters	Meters	
27	Belgium	Ghlin	Cie. des Mines du Nord du Flénu	1	3.65	1874	1885	322	35	Cased provisionally through quicksand and gravel between 285 and 320 m.
28			Ditto	1	3.65	1874	1885	323.75	35	
29	France	Liévin	Cie. des Mines de Liévin	1	3.65	1874	1875	95.5		
30		Bruay	Cie. des Mines de Bruay, Shaft No. 4	1	3.65	1874	1876	118.3	15	Provisional casing in the blue marls between 60.5 and 84.5 m.
31		Auchel	Cie. des Mines de Marles, Shaft No. 4	1	3.65	1874	1875	112.9	6.1	Ditto between 83.3 and 89.4 m.
32		Waziers	Cie. des Mines d'Aniche, Bernicourt Shaft	1	3.20	1874	1875	90	41	Sunk by hand to 21 m. with wooden cuvelage. Provisional casing between 21 and 41 m.
33		Onnaing	Cie. des Mines de Crespin-lez-Anzin	1	3.65	1875	1876	109	14	Cased down to 14m.
34		Dax	Cie. des Mines des Dax	1	1.83	1875	1878	40	40	Cased in quicksand and gravel to depth of 40 m.
35	Belgium	Bracquegnies	Cie. des Mines de Bracquegnies	1	3.96	1875	1878	195		

NOTE.—One meter = 3.28087 ft.

TABLE NO. 1.—LIST OF SHAFTS SUNK BY THE KIND-CHAUDRON SYSTEM TO 1904—*Continued.*

No.	Country.	Place.	Name of Company.	No. of Shafts	Diam. of Shaft.	When Sunk. Begun	When Sunk. Completed.	Depth of Shaft.	Thickness of Loose Ground Requiring Temporary Lining.	Remarks.
					Meters			Meters	Meters	
36	Germany	Merlebach	Saar- u. Mosel-Bergwerks-Ges., Shaft No. 5	1	3.65	1875	1878	165	40	Provisional casing in buntsandstein between 70 and 110 m.
37	France	Dorignies	Cie. des Mines de l'Escarpelle, Shaft No. 5	1	3.65	1876	1877	109	16	Provisional casing down to 16 m.
38		Marly	Cie. des Mines de Marly	1	3.65	1876	1877	57	6	Provisional casing in blue marls between 26 and 52 m.
39	England	Huntington	Cannock Huntington colliery	1	4.58	1876	1881	130	16	Provisional casing in red clays from 14 to 130 m.
40			Ditto	1	4.58	1876	1881	130	16	
41	Belgium	Bracquegnies	Cie. des Mines de Bracquegnies	1	3.65	1876	1879	200		
42	France	Bruay	Cie. des Mines de Bruay, Shaft No. 5	1	3.65	1877	1878	136.35	25	Provisional casing in blue marls between 68.25 and 93.25 m.
43	England	Whitburn	Whitburn Colliery, Shaft No. 1	1	3.65	1877	1879	116.5		Sunk near the ocean beach.
44			Ditto, Shaft No. 2	1	4.00	1879	1881	117.6		
45	Belgium	Maurage	Cie. des Mines de Maurage	1	4.00	1882	1885	261.4	2	Provisional casing from 257 to 259 m.
46	Germany	Derne	Bergwerks-Ges. Gneisenau, Shaft No. 1	1	3.65	1882	1885	241.6		Sunk by hand to 105 m.

NOTE.—One meter = 3.28087 ft.

TABLE No. 1.—LIST OF SHAFTS SUNK BY THE KIND-CHAUDRON SYSTEM TO 1904—*Continued.*

No.	Country.	Place.	Name of Company.	No. of Shafts	Diam. of Shaft.	When Sunk. Begun	When Sunk. Completed.	Depth of Shaft.	Thickness of Loose Ground Requiring Temporary Lining.	Remarks.
					Meters			Meters	Meters	
47	France	Malbosc	Cie. des Mines de Rochebelle	1	3.25	1883				Sunk by hand to 150 m. Abandoned in 1873 because of drowning out of pumps. Sunk by boring to 195 m., and again abandoned in 1885
48	Germany	Derne	Bergwerks-Ges. Gneisenau, Shaft No. 2	1	3.65	1884	1886	244		Sunk by hand to 105 m.
49	France	Oignies	Cie. des Mines Douaisienne	1	2.3	1884	1885	90		
50	Germany	Eisleben	Mansfelder Gewerkschaft, Clotilde shaft	1	3.65	1884	1887	278		Ditto to 240 m.
51		Leopoldshall	Herzogl. Salzwerks-Direktion, Leopoldshall	1	3.65	1887	1889	125.75	10	Provisional lining between 95 and 105 m.
52		Thiede	Gewerkschaft Thiederhall	1	3.20	1887	1889	116.55	58	Ditto, 50 and 108 m.
53		Spittel	Saar- u. Mosel-Bergwerks-Ges., Shaft No. 6	1	3.65	1888	1890	180		
54	France	Quiévrechain	Cie. des Mines de Crespin-lez-Anzin	1	2.5	1890	1893	161	35.5	Ditto, in quicksand and gravel to 35.5 m.
55		Masny	Cie. des Mines d'Aniche, Vuillemin shaft	1	4.25	1891	1892	110	8	Ditto between 6 and 14 m.
56	Germany	Bodelschwingh	Gewerkschaft der Zeche Westhausen	1	2.75	1891	1893	176		Sunk by hand to 150 m.
57		Gahmen	Harpener Bergbau A.-G., Zeche Preussen I, Shaft No. 1	1	4.1	1892	1895	342		Ditto, 150 m.

NOTE.—One meter = 3.28087 ft.

TABLE No. 1.—LIST OF SHAFTS SUNK BY THE KIND-CHAUDRON SYSTEM TO 1904—*Continued.*

No.	Country	Place.	Name of Company.	No. of Shafts	Diam. of Shaft.	When Sunk. Begun	When Sunk. Completed	Depth of Shaft.	Thickness of Loose Ground Requiring Temporary Lining.	Remarks.
					Meters			Meters	Meters	
58	Germany	Jessenitz	Mecklenburgische Kalisalzwerke, Jessenitz	1	3.15	1893	1900	310		Sunk by hand to 150 m. Provisional lining in gypsum from 253 to 263 m.
59		Kreuzwald	A.-G. La Houve, Strassburg, Marie mine	1	3.65	1896	1898	150		
60		Rauxel	Gewerkschaft der Zeche Viktor, Shaft No. 2	1	4.4	1896	1898	300		Ditto to 240 m.
61		Mengede	Mengeder Bergwerks-A.-G., Zeche Adolf von Hansemann	1	4.4	1896	1898	260		Ditto to 190 m.
62		Derne	Harpener Bergbau A.-G., Zeche Preussen II, Shaft No. 1	1	4.1	1897	1900	373		Ditto to 233 m.
63			Ditto, Shaft No. 2	1	4.4	1897	1901	368		Ditto to 260 m.
64		Tiefenort	Gewerkschaft Kaiseroda	1	3.65	1897	1899	203	50	Ditto to 148 m. Provisional lining from 145 to 196 m.
65		Lübtheen	Gewerkschaft Friedrich Franz, Lübtheen	1	3.65	1897				Still sinking
66		Kochendorf	Königl. Würtemberg, Saline Friedrichshall	1	4.4	1898	1899	117		Sunk by hand to 96 m.
67		Dortmund	Harpener Bergbau A.-G., Zeche Scharnhorst, Shaft No. 1	1	4.1	1899	1900	140		Ditto to 112 m.

NOTE.—One meter=3.28087 ft.

TABLE No. 1.—LIST OF SHAFTS SUNK BY THE KIND-CHAUDRON SYSTEM TO 1904—*Concluded.*

No.	Country.	Place.	Name of Company.	No. of Shafts	Diam. of Shaft.	When Sunk. Begun	When Sunk. Completed.	Depth of Shaft.	Thickness of Loose Ground Requiring Temporary Lining.	Remarks.
					Meters			Meters	Meters	
68	Germany	Kreuzwald	A.-G. La Houve, Strassburg, Shaft No. 2	1	3.65	1900	1901	108		
69		Benthe	Gewerkschaft Wallmont, Hanover	1	4.1	1900	1901	205	36	Sunk by hand to 162 m.
70		Diekholzen	Gewerkschaft Hildesia, Hanover	1	4.1	1900	1904	353	37	Ditto to 185 m.
71		Berka	Gewerkschaft Alexandershall, Hamburg	1	4.1	1900	1902	166	40	Ditto to 95 m.
72		Dietlas	Gewerkschaft Grossherzog von Sachsen	1	4.1	1901	1904	412	25	Ditto to 340 m.
73	France		Cie. des Mines Ferques à Rinxent	1	3.65	1901		330		Ditto to 160 m.
74	Germany	Sehnde	Friedrichshall Aktien-Gesellschaf	1	4.1	1902	1904	192	36	Ditto to 32 m.
75		Rauxel	Gewerkschaft Viktor, Shaft No. 3	1	4.1	1902	1903	336		Ditto to 255 m.
76		Hanover	Alkaliwerke Ronnenberg	1	4.1	1902	1904	192	45	Sunk to 125 m. by the freezing process
77	England	Dover	Consol. Kent Collieries Corp., London	1	4.4	1902		365	Still sinking	Sunk by hand to 320 m.
78	Belgium	Maurage	Société Anonyme des Charbonnages de Maurage et Boussoit	1	3.0	1902		265		
79	Germany	Hanover	Gewerkschaft Hansa Silberberg	1	2.5	1904		165		Sunk to 111 m. by the freezing process

NOTE.—One meter = 3.28087 ft.

III.

THE FREEZING PROCESS.

Readers of the preceding chapter on shaft-sinking by boring may have been impressed by the radical views advanced and the audacity of some of the processes described. The subject can be properly appreciated, however, only by considering the state of affairs preceding the development of these methods. At that time shaft-sinking in hard rock, when the inflow of water was too great to be raised by pumping, was practically hopeless. Great interest was therefore excited by Kind's proposal to bore a shaft under water in its full cross-section, in exactly the same manner as a prospecting drill-hole is put down, and, while still under water, to install a water-tight cuvelage after the sinking had reached its total depth. Such shafts, as already stated, are now sunk to depths as great as 400 m. (1312 ft.). In the early history of the process the shafts were lined with wooden tubbing, but with very uncertain results. Chaudron first suggested cast-iron cuvelages, together with the epoch-making method of lowering them into place, which has become a striking and permanent feature of shaft-sinking by boring. To the joint efforts of Kind and Chaudron, associated in the "Société Anonyme de Foncage des Puits Kind-Chaudron", is due the remarkable success, in so short a time, of perfecting a system which has never yet failed.

In the more recent freezing system an equally bold and original idea was developed. F. H. Poetsch, who brought out the method in 1883, was not the first in the field, however, as a small shaft had been sunk in Wales in 1862 by alternately freezing the ground with coils of refrigerating-pipe and excavating the frozen material in small sections. A similar method has been and is still employed in Siberia, where the rigor of the climate is utilized by allowing the shaft-bottom to freeze time after time and excavating the frozen soil. In this way shafts are sunk in sand to depths of 24 m. (79 ft.), though they are usually much shallower. Similar means are employed, also, in sinking through the water of rivers. A wooden crib or coffer-dam is sunk in the autumn, and secured inside and out by broken stone. During the winter the frozen material inside the crib is excavated in sections until the bed of the river is reached.

Those interested in the early history of the freezing process will find many details in the article by F. Schmidt of Paris, printed in the "Zeitschrift für die gesammte Kälteindustrie", in 1898 (R. Oldenburg, publisher, Munich), and entitled "The Utilization of the Freezing Process in Mining Operations".

This process is applicable to soft and unstable ground, containing large quantities of water, in which ordinary hand-sinking cannot be carried on. The watery soil is frozen solid. and thus made impermeable, after which the shaft is sunk by drilling and blasting.

The original Poetsch process, which remains essentially unchanged, consisted in sinking a series of pipes somewhat outside of the circumference of the proposed shaft, and then circulating through them a freezing solution. A cylinder of frozen ground of gradually increasing diameter is thus formed

around each pipe. As the pipes are usually not more than 80 to 100 cm. (31 to 39 ins.) apart, the columns of frozen material soon come into contact and overlap one another, thus forming a continuous cylindrical wall of ice. By continuing the freezing the thickness of the wall will increase, until the entire mass is frozen solid to the center. Interesting details concerning the process are included in the essay of F. Schmidt, already cited.

On completing the freezing, sinking is started by handwork, even light blasts being admissible. Earlier attempts to sink by thawing the core of the frozen mass with steam have never been seriously considered. The frozen condition of the material is not particularly obstructive to the work of sinking, except that in some cases the drilling of holes for blasting is rather difficult. Sinking is usually carried on in sections, each section being lined with masonry, or for considerable depths, with tubbing. The annular space between the lining and the frozen ground was formerly filled with slack coal as a non-conductor, then dry concrete was used with the idea that it would become wet and set as the ground thawed out; and later still, in order to secure rapid setting, wet concrete mixed with alkalies has been employed. The junction with the hard, impervious ground below is usually accomplished by walling- and wedging-cribs. The method has had many successes and also numerous failures, the latter due in part to inexperience in conducting the work, in part to the general ignorance concerning the factors controlling the applicability of the process, which could only be determined by trials at various places and under dissimilar conditions.

The maximum limit of depth depends somewhat on physical and various local conditions, which cannot yet be clearly

defined in any general terms. Recent researches in physics have shown that the limiting forms of body of various substances are by no means so well defined as was originally supposed. For instance, solid bodies, even rocks, may under pressure be brought to a plastic state and caused to flow, or change their form, without losing their nature or physical identity. Observation of such facts has given rise to various mechanical processes, such as the drawing of pipes (particularly lead pipe), which is accomplished by the co-operation of heat and pressure. Nor is ice an absolutely rigid body; on the contrary, it becomes plastic at comparatively small pressures and can be caused to change its shape without the preliminary process of thawing. Some years ago the author showed that by a pressure of 20 atmospheres pure ice at $-20°$ C. could be run into solid rods, through quite small openings. This means that a mass of ice at a depth of 200 m. (656 ft.) would be as plastic as clay, and could no longer retain its form or place without support.

Naturally the conditions of plasticity would require much greater pressure (or depth below the surface) if the frozen material were not pure ice, but a mixture of water and clay or sand, in which the internal friction between the constituent particles would be greater and the pressure necessary to produce flow much higher. The same would be true when small areas or masses of pure ice fill cavities or fissures in hard ground.

It is a well-known fact that the freezing-point of water is lowered by dissolving soluble salts therein. The freezing-point drops more or less according to the kind and amount of material dissolved, and the ice formed is less compact and softer than pure ice. Evidently, when under pressure the plasticity of such ice is much greater than when pure. It is also well known

that, as the temperature falls, the hardness of all bodies increases rapidly as the point of solidification is approached, and that the rate of such increase in hardness diminishes as the temperature of the substance becomes lower.

There is no reason to believe that ice forms an exception to this general rule governing nearly all substances, but that it also passes on melting through a softening process. It may therefore be assumed that physical conditions will not be materially altered by the adoption of lower freezing temperatures, and I am consequently of the opinion that the hopes based on the so-called low-temperature processes have but slight basis. From the above considerations it is clear that attempts to adopt the freezing process for great depths must be made with caution, because there is in all cases an ultimate depth below the surface which distinctly limits its sphere of usefulness.

The deepest shaft planned to be sunk by the freezing process is that of Schieferkaute, which will have to be frozen to a depth of 240 m. (787 ft.). The general conditions are favorable, as a firm and compact argillaceous sand carrying but little water is the lowest bed to be frozen. Although the material to be traversed will be hard and compact it is quite likely that some valuable conclusions as to the ultimate applicability of the freezing method may be reached. As Haniel & Lueg have the contract for this work, the author will be afforded opportunity for investigating further the matters discussed above.

The freezing system has found its most frequent applications in Germany and France, and it is in the latter country that it has been employed for the greatest depths. The earlier details of the method may be omitted here, as they are of historical interest only. They have been elaborately described in Schmidt's

essay, so that we shall confine ourselves to such of the modern developments as are of practical importance.

Shaft-sinking of the Gewerkschaft "Hansa Silberberg", at Empelde, near Hanover. (Plates XII and XIII.)

Two bore-holes were sunk which showed the following strata:

Surface soil	0.0– 2.0 m.	(0 – 6.5 ft.)
Quicksand	2.0– 2.5 m.	(6.5– 8.2 ft.)
Clay	2.5– 16.0 m.	(8.2– 52 ft.)
Quicksand	16.0– 22.0 m.	(52 – 72 ft.)
Lignite	22.0– 24.0 m.	(72 – 79 ft.)
Quicksand	24.0– 34.0 m.	(79 –111 ft.)
Gravel	34.0– 46.0 m.	(111 –151 ft.)
Clay and sand	46.0– 80.0 m.	(151 –262 ft.)
Gypsum	80.0–133.0 m.	(262 –436 ft.)
Rock-salt	133.0 m.	(436 ft.)

The dip of the strata averages 40° and the drill-holes proved conclusively that many difficulties might be anticipated.

Ground was broken on November 7, 1896, and work started with a masonry drop-shaft provided with a cast-iron shoe 8.95 m. (29.35 ft.) outside diameter. The shoe was of the usual design, well bolted together and fastened to the masonry of the shaft. The drop-shaft was somewhat tapered and sheathed with planed planking on the outside to reduce friction in sinking. It was sunk to a depth of 12½ m. (41 ft.) and stopped in the clay seam. Under it was built a masonry footing, in which the anchoring for the base-ring of the hydraulic jacks was embedded. An inner lining was then installed, in the upper part of which was set the pressure-ring for the jacks. This ring was connected with the lower anchoring by means of 30 iron rods, each 65 mm. (2.5 ins.) in diameter. The inner masonry lining was then continued to the surface. Ten vertical I beams, of

standard cross-section (German No. 15), each 6 m. (20 ft.) long, were built into the inner surface of the drop-shaft, leaving a net inside diameter of shaft of 5.9 m. (19.35 ft.). These I beams were to serve as guides for the iron drop-shaft, the first ring of which, after the completion of the above preliminaries, was put in place in the bottom of the excavation. The outside diameter of the iron drop-shaft was 5.84 m. (19.15 ft.), inside diameter 5.5 m. (18 ft.); each ring consisting of 10 sections, 1.5 m. (4.9 ft.) in height. The cast-steel shoe was 5.86 m. (19.21 ft.) in diameter at the cutting edge. Thirty hydraulic jacks, each of 100 tons capacity, were used to force down the drop-shaft. They were operated from a suspended platform.

Excavation was carried on by means of the well-known sack-borer, provided with hollow rods, terminating above in a heavy section of rod, to which the customary operating machinery was connected. The borer was not provided with bags, being used merely to loosen the ground, which was then raised to the surface by means of a Priestman dredge.

Down to a depth of 25 m. (82 ft.) the iron drop-shaft sank by its own weight, farther advance being effected by means of the jacks. When the shoe reached a depth of 37 m. (121 ft.) it became impossible to force it any lower, notwithstanding that the shaft bottom was undercut by means of the borer, and the top of the shaft loaded with a weight of 2500 tons. Several abortive attempts resulted only in a break, which caused the shaft to settle out of plumb.

Work was then started to sink another inner drop-shaft, measuring 4.5 m. (14.76 ft.) in the clear. This also had a steel shoe and was built of 10-section rings, 70 mm. (2.73 ins.) in thickness. The pressure-ring for the jacks was correspondingly reduced in diameter and work continued as before. The

shoe of this shaft was successfully sunk to a depth of 62 m. (203 ft.). There the shaft stuck fast, and after many futile attempts to force it farther it was decided to continue sinking by hand. A mass of concrete, 1.5 m. (4.9 ft.) in depth, was placed in the bottom and the shaft pumped out. The upper portion of the ruptured lining was then calked and reinforced, and several test drill-holes put down through the concrete. They showed that one third of the sump area was underlaid by quicksand and two thirds by clay, to a depth of 6 or 7 m. (19.7 to 23 ft.) below the concrete, i.e., as far as the holes were drilled.

This precluded sinking by hand, so that it was decided to adopt the freezing process, and a contract for the work was let to the firm of L. Gebhardt of Nordhausen. Fourteen freezing-pipes were sunk inside of the last 4.5-m. (14.76-ft.) drop-shaft, in a circle 4.15 m. (13.6 ft.) diameter, and to a depth of 56 m. (184 ft.) below the shaft bottom, or 115 m. (377 ft.) from the surface.

It was planned to sink an advance shaft in the frozen ground to the 115 m. (377-ft.) level, and there enlarge the excavation sufficiently to put in a wedging-crib, 4.5 m. (14.76 ft.) in the clear, i.e., of same diameter as the second drop-shaft. Then the frozen material was to be cut out upwards by stages, and tubbing put in place outside the circle of freezing-pipes as the work advanced. This plan was based on the assumption that, after stopping the ice-machine, the frozen ground would stand long enough to permit the completion of the work. It was adopted in order to save time and the expense of a large number of freezing-pipes. Had the pipes been sunk from the surface, outside of the circumference of the shaft, 26 instead of 14 would have been required. For these pipes it would

have been necessary to drill 26×115=2990 m. (9807 ft.) instead of the 14×56=784 m. (2571 ft.) as proposed. The saving in cost of 2206 m. at 45 marks per meter would be 99,270 marks ($24,818). The sinking of the freezing-pipes inside the shaft was not so easy as had been anticipated, but to have started them from the surface would have required more piping, and the passage through the bed of gravel lying between 36 and 45 m. (118 and 147 ft.) promised to be difficult.

The old bed of concrete in the shaft-bottom having been cracked in drilling the test-holes, an additional 1.5 m. (4.9 ft.) of concrete was deposited upon it. An annular cast-iron box crib, 3.5 m. (11.5 ft.) inside diameter, was then put in as a template for the 14 bore-holes; flanged guide-pipes 6 m. (19.7 ft.) long were bolted to the template, which was then covered with 1 m. (3.28 ft.) of concrete. Six of the pipes were continued clear to the surface, the others being closed with caps. In four of the pipes reaching the surface, boring for the freezing-pipes was begun. On completing these the stand-pipes were shifted for another set of holes until all had been bored. At first one boring-machine was used, but afterward two. It was originally intended to close the lower ends of the freezing-pipes and lower them into the bore-holes without putting in casing, but the presence of sandy strata at 95 to 100 m. (312 to 328 ft.) made it necessary to case the holes. The freezing-pipes purchased were therefore utilized as casing by leaving them open at the bottom. The pipes actually used for freezing were 128 mm. (5 ins.) outside diameter and 110 mm. (4.29 ins.) inside by 5 m. (1.64 ft.) long, joined by screw-couplings and tested for a pressure of 25 atmospheres. Their lower ends were left open, as some of them had to be sunk with the aid of water-jets. They were ultimately closed by special cast-iron

plugs which were screwed into place from the surface by the use of long rods.

Each casing was pulled out after a freezing-pipe had been lowered into the guide- or stand-pipe, which reached to the surface, and steps were taken to pack the freezing-pipes in the latter. This was done by lowering conical cast-iron rings, covered with rubber packing, around each freezing-pipe and into the corresponding hole in the cast-iron guide-plate already mentioned, which holes tapered downwards. Then two conical lead rings, fitting closely into each other, were put in position and rammed tight around the freezing-pipe. Finally, all the guide-pipes were removed, together with the continuations of the freezing-pipes above the point where the connections for the distribution of the freezing solution were to be installed. For additional safety a stuffing-box was screwed on top of each guide-pipe, thereby rendering all the freezing-pipes doubly secure against leakage. At 42 m. (138 ft.) below the surface two annular conduits, one for the introduction of the freezing solution, the the other for conveying it away, were put in place and connected up respectively with the inside and outside freezing-pipes. From these conduits pipes led to the refrigerating-plant on the surface. The details of the shaft and piping are given on Plate XIII, which shows the equipment as it was at the end of 1901.

The refrigerating-plant was an ammonia machine, working on the Linde system. It consisted of a 500 mm. by 1000 mm. (19.5×39 ins.) single-cylinder steam-engine, connected to the compressor through the fly-wheel shaft and driving the auxiliary apparatus by belting. There were two condensers and two refrigerators, respectively 1.8 and 2 m. (5.9 and 6.56 ft.) in diameter by 3 m. (9.84 ft.) high; also a pump of 70 cbm.

(18,480 galls.) capacity per hour for circulating the solution, and an apparatus for removing oil from the ammonia gas. A solution of magnesium chloride was the freezing medium used. Plate XII is a plan of the equipment.

The plant was started May 21, 1899. On June 18th the work was interrupted by the bursting of the freezing-pipes one after another, so that the solution, at a temperature of 21° C., leaked out into the surrounding soil. The inner or feed pipes were therefore removed and the damaged pipes lined with others, in each of which a special feed and return pipe were placed. These are shown in the middle figure of Plate XIII.

After starting the plant again, actual sinking was commenced August 1, 1899. The concrete bottom was pierced and the soil found to be well frozen. As sinking advanced the walls were lined with beech sheathing, 25 mm. (1 in.) thick, held in place by flat iron rings, 3.45 m. (11.3 ft.) clear diameter, suspended one from another 1 m. (3.28 ft.) apart by rods and hooks. Compressed powder was used as explosive, and, at a daily advance of 3 to 4 m. (10 to 13 ft.), a depth of 78½ m. (257 ft.) was reached on September 14, 1899. At that point water commenced to percolate through the bottom of the shaft. While the origin of this inflow was under investigation, a flood of 40 cbm. (10,560 galls.) per minute suddenly broke through, so that the men were rescued with difficulty. Attempts at unwatering made between October 21st and November 15th were abortive, showing that the ground was not completely frozen. Two additional freezing-pipes were therefore put down to a depth of 78 m. (256 ft.) and, unwatering being eventually accomplished, work was resumed on December 23, 1899. The shaft was relined with channel-iron supports and cleared of ice. At a depth of 76 m. (250 ft.) the mine inspector's office

insisted that 28 more prospecting drill-holes be sunk to the underlying gypsum strata, in order to safeguard the men. On February 23, 1900, at a depth of 79½ m. (261 ft.) one of these holes showed so much water that it was plugged with difficulty. While considering the best course to pursue, a sudden inflow

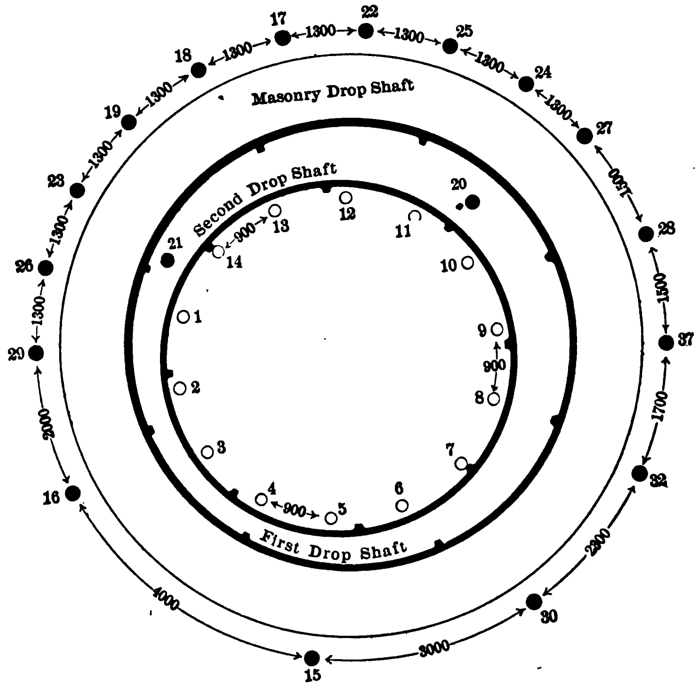

FIG. 8.—Arrangement of freezing-pipes at Hansa-Silberberg. Nos. 1–14, original freezing-pipes. Nos. 15–32, supplementary freezing-pipes, installed after the break.

occurred on the night of February 28th, while the shift was off. The inburst filled the shaft with mud and sand, up to the 62-m (203-ft.) level. Two special freezing-pipes were put down, and this material frozen with a view to reaching the distributing-rings for the solution at the 42-m (138-ft.) level. In each case the irruption had occurred near No. 1 pipe (see

Fig. 8). The next step was to sink two more freezing-pipes (Nos. 15 and 16) outside of the original drop-shaft. After putting them into operation the shaft again filled with sand to the 62-m. (203-ft.) level. This was cleaned out and sinking resumed as before, though with a reduction of shaft diameter, so that the temporary timbering was only 2.9 m. (9.5 ft.) in the clear. On reaching the 76-m. (249-ft.) level (August 31, 1900) water was struck in a drill-hole between pipes Nos. 10 and 11 at a depth of 79 m. (259 ft.), and the shaft rapidly filled for the third time.

Twelve additional freezing-pipes were now put down, outside of the original drop-shaft and to a depth of 115 m. (377 ft.), constituting a second concentric freezing-zone, of larger diameter, although, as shown by Fig. 8, not quite continuous. These new pipes were connected with the refrigerating-plant and the second freezing belt completed.

After allowing sufficient time for the ground to freeze sinking operations were resumed with a diameter of 2.9 m. (9.5 ft.), and at a depth of 86.2 m. (283 ft.) the shaft entered the gypsum. This was considerably below the place where the former breaks had occurred, the ground there having been saturated with the freezing solution. Work was started on the wedging-crib, when, on December 28, 1901, another inrush of unfrozen material occurred at a depth of 80 m. (262 ft.), between pipes Nos. 1 and 3, at the point where the ground had previously been saturated with the solution. The exact position of the break could not be determined, as the shaft-walls were lined and the lights were extinguished by the violence of the inflow. Thus the shaft filled with water for the fourth time, a deposit of 4 m. (13 ft.) of sand settling in the bottom.

Early in February, 1902, a new contract was made, whereby the time limit for completing the work to 115 m. (377 ft.) was extended nine months, and, as the company declined to bear the additional expense, the entire cost was thrown on the contractor. The latter then put down three new freezing-pipes (Nos. 33, 34, 35) in the spaces in the outer series between pipes Nos. 16 and 29 and pipes Nos. 15 and 16 (see Fig. 8). None was sunk in the space between Nos. 15 and 30. Additional pipes were also placed inside the shaft-area proper, in the manner already described, and all were connected up with the refrigerating-plant.

After cleaning out the shaft to the 61-m. (200-ft.) level, an advance excavation, 2.7 m. (8.8 ft.) in the clear, was sunk to a depth of 87 m. (285 ft.). This was afterward enlarged, a wedging-crib put in, and the shaft lined with tubbing to the 61.5-m. (202-ft.) point, without, however, making a water-tight connection with the upper lining. Sinking was then continued below 87 m. (285 ft.), and the walls of the shaft supported by suspended tubbing-rings as the work advanced, until a depth of 101.5 m. (366 ft.) was reached, at which point a second wedging-crib was installed. On sinking below that point to 115 m. (377 ft.) the shaft was again flooded (October 6, 1902), just as preparations were being made to place still another wedging-crib.

Since the date last named the shaft has been under water; but the completion of the work by means of the boring method has now been decided upon, and Haniel & Lueg, to whom the contract had been awarded, will soon begin operations.

THE SINKING OF SHAFT NO. 6, OF THE HERZOGLICH ANHALTISCHE SALZWERKS-DIREKTION, AT LEOPOLDSHALL, STASSFURT. (PLATE XIV.)

The character of the ground at the point selected for the shaft was rather unfavorable, as is shown by the following section obtained from bore-hole No. 13:

Surface soil	0.0– 1.0 m.	(0– 3 ft.)
Gravel	1.0– 6.8 m.	(3– 22 ft.)
Sand	6.8– 7.8 m.	(22– 25 ft.)
Quicksand	7.8– 11.2 m.	(25– 36 ft.)
Sand	11.2– 12.2 m.	(36– 40 ft.)
Gravel	12.2– 13.0 m.	(40– 43 ft.)
Coarse gravel and boulders	13.0– 15.2 m.	(43– 50 ft.)
Sand, in parts cemented	15.2– 21.0 m.	(50– 69 ft.)
Reddish gray clay	21.0– 24.0 m.	(69– 79 ft.)
Buntsandstein, gravel, and boulders	24.0– 29.5 m.	(79– 95 ft.)
Buntsandstein, with oölitic rock	29.5– 48.5 m.	(95– 159 ft.)
Red and blue marls	48.5– 90.0 m.	(159– 295 ft.)
Red and blue marls with oölitic rock and thin beds of sandstone	90.0–265.0 m.	(295– 869 ft.)
Ditto, alternating with beds of indurated clay	265.0–330.0 m.	(869–1082 ft.)
Ditto, with layers of gypsum	330.0–335.0 m.	(1082–1099 ft.)
Anhydrite and saliferous clay	335.0–379.0 m.	(1099–1243 ft.)
Potash salts	379.0–394.0 m.	(1243–1292 ft.)
Rock-salt	394.0–100.0 m.	(1292–1312 ft.)

The natural ground-water level is 1.3 m. (4 ft.) below the surface.

The management planned to begin work with a drop-shaft, and to this end consulted with the firm of Haniel & Lueg. The latter, however, feared that difficulty would be met in sinking through the gravels and boulders, and, when presenting their estimates, advised consideration of the freezing process, recommending Messrs. Gebhardt & Koenig, of Nordhausen, as con-

tractors for carrying out the work. To this firm a contract was eventually let, the management at the same time arranging with Messrs. Haniel & Lueg for the necessary tubbing.

The freezing-pipes, twenty six-in number, were sunk early in 1899. They were placed somewhat less than 1 m. (3.28 ft.) apart, in a circle 8 m. (26 ft.) in diameter, and were put down to a depth of 100 m. (328 ft.). Considerable difficulty and delay were experienced in passing through the gravel and boulders, so that the refrigerating-plant could not be connected up and started until June 22, 1900. Details of the freezing-plant may be omitted here, and reference made to Figs. 9, 10, and 11, and Plate XIV.

By September 12, 1900, the unwatering and cleaning out of the shaft were completed, only a small leakage of water being noticed in the center of the sump. But at 8.30 A.M. on September 19th water broke through the bottom at 9.5 m. (31 ft.), so that work had to be stopped and the shaft allowed to fill. It may be noted here that bore-holt No. 13, mentioned above, was put down within the area chosen for the shaft and may have facilitated the inflow of water. It was evident, at least, that the shaft had not been completely frozen to the center. The progress of the freezing was delayed by the presence of impurities in the calcium-chloride solution, chiefly sulphate of soda, which was deposited at the low temperature on the inner walls of the freezing-pipes and impeded circulation. On resuming work the temperature of the solution was −17° C. when passed down through the pipes, and −13° to −14° C. on returning to the surface. Later these temperatures were respectively −21° and −18° C. The shaft was again unwatered by the end of November, 1900, and sinking resumed early in December, 1900. At first only picks and shovels

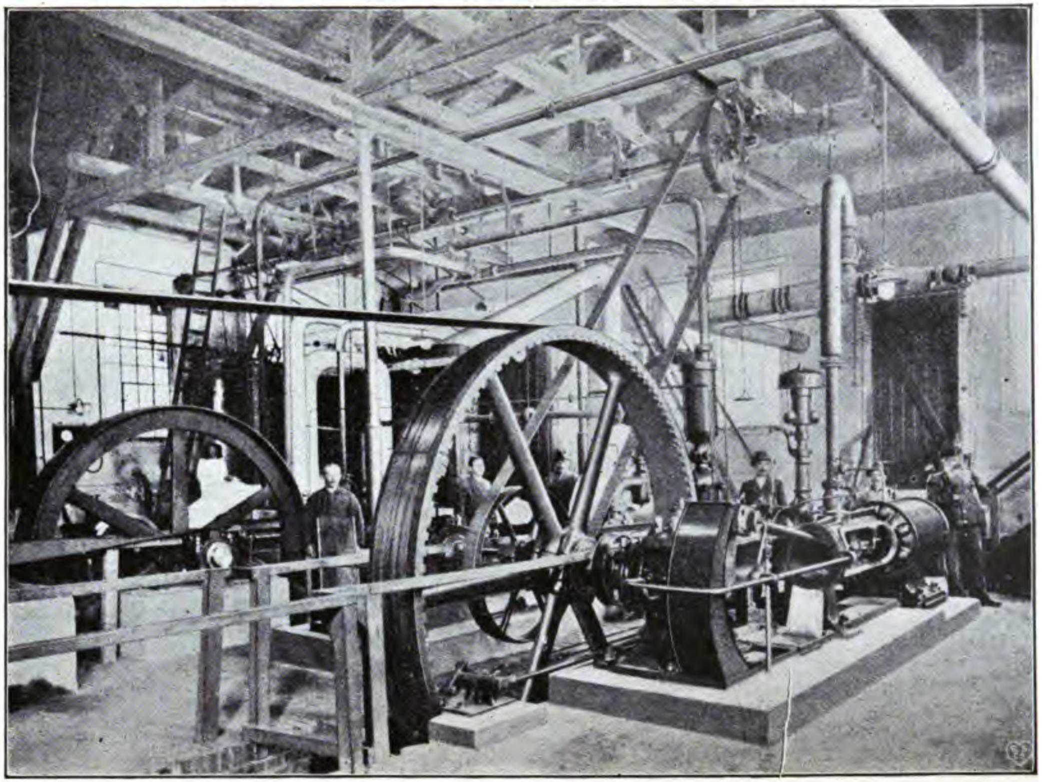

Fig. 9.—Shaft No. 6, Herzoglich Anhaltische Salzwerks-Direktion.
General View of the Freezing-plant,

were used; afterward blasting with compressed powder gave satisfactory results. In the gravel and boulders the work was difficult. The advance in December was 14.2 m. (46 ft.); in January, 1901, 22.7 m. (74 ft.), and February, 24.6 m. (80 ft.). At a depth of 71.5 m. (234 ft.) evidences of pressure and instability of the shaft-walls appeared, so that it was decided to put in a lining of permanent tubbing, in spite of the fact that no solid ground for setting the wedging-crib had yet been reached. However, a crib 0.5 m. (1.6 ft.) in width was placed at 71 m. (233 ft.), upon which the tubbing-rings were built up, with another crib, also 0.5 m. (1.6 ft.) wide, interpolated at 58.7 m. (192 ft.)

At depths of 40.43 and 21.93 m. (133 and 72 ft.) still other supporting-rings were put in. The spaces behind the wedging-cribs were filled with concrete, consisting of equal parts of cement and sand, while the tubbing was backed by a mixture of one part cement, one part broken brick, and two parts gravel. These concretes were mixed with a warm 10–12% solution of calcined soda. For each meter in depth of shaft there were consumed 10 barrels of cement, 106 kg. (233 lbs.) of soda, 0.6 cbm. (¾ cu. yd.) of sand, 1.25 cbm. (42 cu. ft.) of brick, and 2.5 cbm. (3¼ cu.yds.) of gravel.

On April 19, 1901, sinking was resumed, and by the end of the month 7.9 m. (26 ft.) had been made. The erecting of the tubbing was begun on May 3d, a wedging-crib being set at 80.33 m. (363 ft.). This work was completed May 16th and sinking was again resumed on the 17th, a total advance of 10.07 m. (33 ft.) being recorded for May. By the middle of June 13.2 m. (43 ft.) more had been made and the shaft lined with tubbing between the depths of 101.66 m. and 80.33 m. (333 and 363 ft.). The ground being difficult, another wedging-

crib, 0.5 m. (1.64 ft.) wide, was set at 92.66 m. (304 ft.), the crib at 101.66 m. (333 ft.) being 0.7 m. (2.3 st.) wide. The method originated by shift-boss Trenkel for supporting the wedging-cribs in difficult ground is rather interesting. As the material was so soft that it would not bear the weight of the cribs, sinking was continued, as shown in Fig. 11, for a distance of 1.5 m. (4.9 ft.) below the point chosen for setting the crib, and the excavation lined with squared timbers of the same thickness as the tubbing and backed by good concrete. On such a foundation the wedging-crib could be safely set. After wedging it into place, concrete was rammed in underneath, so that the tubbing-rings could be built directly upon it. By the completion of this work, on July 4, 1901, the operations of sinking by the freezing process were brought to a successful conclusion.

In view of the bad ground, however, it was decided to continue the freezing while further sinking proceeded, until a reliable and permanent connection could be made with the solid rock. Sinking was therefore carried on in sections, each being promptly lined with tubbing. This procedure was followed until the wedging-crib at 175.32 m. (575 ft.) was reached, and the tubbing-rings above it were in place and joined to the upper portion of the shaft-lining, after which the ice-machine was shut down, on November 8, 1901. Subsequently sinking progressed without difficulty, so that in January, 1902, a depth of 212.8 m. (698 ft.) was reached, where a new wedging-crib was put in place.

In spite of good ventilation and a temperature of 18° C. in the bottom of the shaft, the upper portion of the shaft-walls was still so covered by frost that the ribs of the tubbing were scarcely distinguishable. The entire appearance

FIG. 10.—Shaft of the Herzoglich Anhaltische Salzwerks-Direktion. Closing the Lower and Upper Tubbing Sets in Frozen Ground.

of the work was most satisfactory, especially as regarded the lining.

This shaft may be considered as a very favorable example

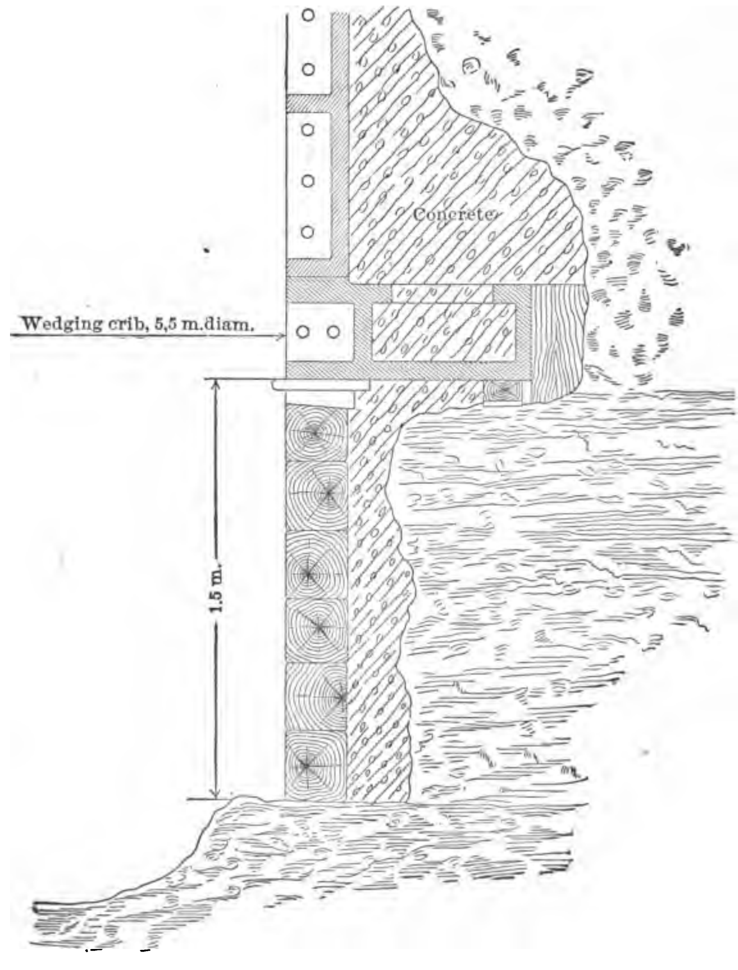

FIG. 11.—Method of Supporting Wedging-cribs in Heavy Ground.

of the results to be obtained by the freezing process, as no serious interruptions occurred and the progress made was

good. For sinking the 175 m. (574 ft.) to the point where freezing was discontinued 2¾ years were required, so that the advance was somewhat more than 5 m. (16.4 ft.) per month for a shaft 5.5 m. (18 ft.) in clear diameter.

Sinking of a Shaft at the Marie Mine, near Atzendorf.

The work was carried to a depth of 50 m. (164 ft.) by sinking two drop-shafts, one telescoping inside the other, but without the use of automatic jacks. It was then decided to introduce the freezing process, notwithstanding that only some 8 m. (26 ft.) remained to be sunk before reaching the coal.

On July 1, 1900, the contractors began to sink the freezing-pipes, 26 in number, 62 m. (203 ft.) deep and arranged in a circle of 8 m. (26 ft.) diameter; that is, they were placed outside of the drop-shafts. The refrigerating-plant was started about the middle of January, 1901, and on June 6th the shaft was unwatered and sinking began. Work proceeded without interruption to the desired depth of 60 m. (197 ft.). The portion of the shaft in the coal was lined with masonry, tubbing being used above that, up to the 5-m. (16.4-ft.) iron drop-shaft. Fig. 12 shows the iron shoe of the drop-shaft at this point, and below it the temporary lining, which was afterward replaced by tubbing. The characteristic vertical fracture in the drop-shaft, plainly visible in the cut, is due to the fact that, while lowering the shaft, inrushes of the soft ground took place, followed by sudden caving of the vacant spaces behind the walls. These matters are discussed in the following chapter on "Drop-Shafts."

By November 17, 1901, work had advanced so far that the refrigerating machinery might have been stopped, had it not

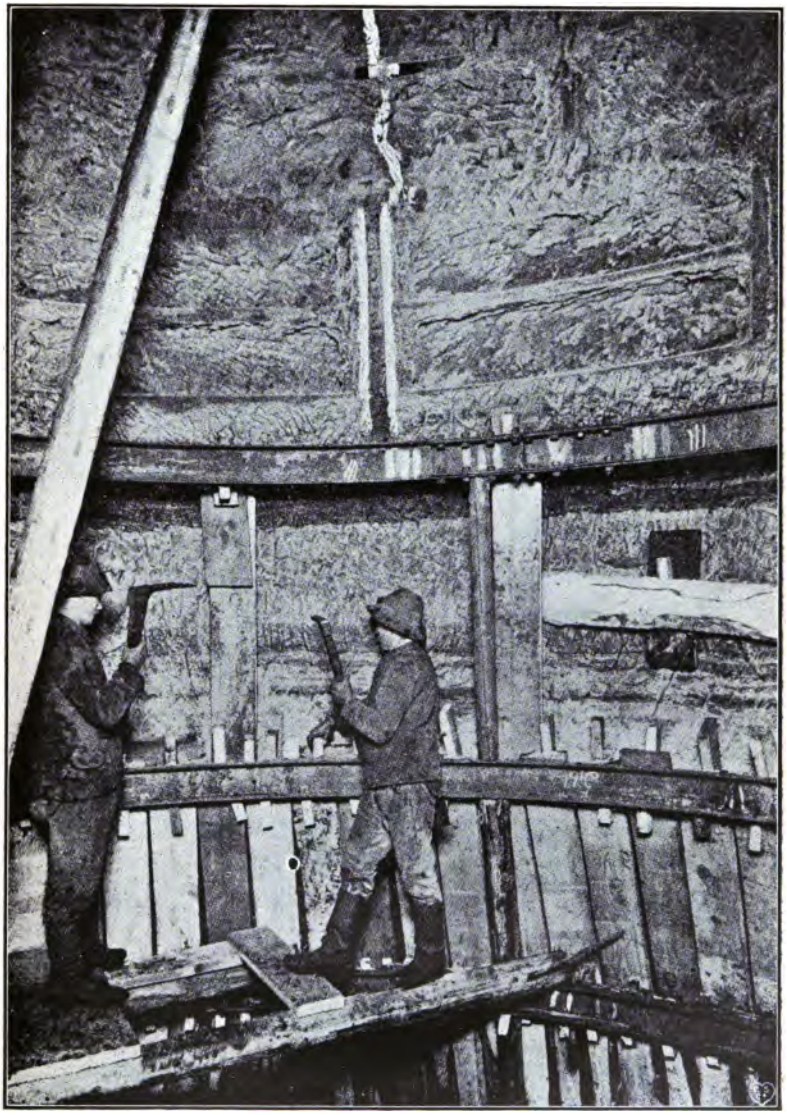

Fig. 12.—Shaft of the Marie Mine, near Atzendorf. Joining the Temporary Lining with the Overlying Damaged Iron Drop-shaft, the Latter being Completely Frozen In.

been desired to cut out a couple of shaft stations under its protection. It was therefore kept in operation until December 7th.

Shaft at the Consolidated Sophie Lignite-mine at Wolmirsleben.

A contract was let for a shaft 5 m. (16.4 ft.) in diameter and 80 m. (262 ft.) deep to the coal-measures. Work was begun with an excavation 8.5 m. (27.9 ft.) in the clear and 3 m. (10 ft.) deep, over which the derrick was erected. The sinking of the freezing-pipes was started on February 9, 1900, the operation of freezing on August 15th, and sinking proper in the latter part of October. The upper portion of the shaft was lined with masonry, built in complete ring-sections, and supported in its lower part by pillar-like masses of masonry. Work was finished on April 24, 1901, the average advance being 5½ m. (18 ft.) per month.

Shaft at the Ronnenberg Potash-mines, near Hanover. (Plate XV.)

This shaft was begun in April, 1898. It was started on top of a bore-hole which had indicated that no difficulty from water was to be anticipated. The upper strata were of clay and argillaceous sands; gypsum, somewhat fissured, occurred at 27 m. (88 ft.), and between 90 and 125 m. (295 and 410 ft.) a bed of Tertiary clay and sand was passed through. Between the latter point and 140 m. (459 ft.) gypsum was again encountered, overlying rock-salt at 140 m. A continuous record had been obtained from the drill-core.

Sinking was started as usual, but at 8 m. (26 ft.) the bore-

hole in the center of the shaft-bottom admitted a flow of from 1 to 1½ cbm. (264 to 396 galls.) of water per minute. The hole was plugged, but at 17 m. (56 ft.) the water again broke through at the rate of 3½ or 4 cbm. (924 to 1056 galls.) per minute. As the work advanced in the plastic clay below the 11-m (36-ft.) horizon, beds of sand occurred with greater and greater frequency. The clay itself also contained a larger proportion of sand, so that the putting in of satisfactory provisional timbering became increasingly difficult. Steps were therefore taken to install a cast-iron drop-shaft, notwithstanding that gypsum was to be expected at a depth of 25 m. (82 ft.). But in sinking the drop-shaft (which was 6 m. or 19.7 ft. inside diameter), so many difficulties and obstacles were encountered that attempts to shut out the water proved fruitless. The material was excavated by hand, the water being pumped out, but at 27 m. (88 ft.), where the shoe of the drop-shaft was all in gypsum, the flow of water reached 15 cbm. (3960 galls.) per minute. Pumping, originally with duplex pumps, was later done with Pulsometers, which were very satisfactory in dealing with the sandy water. After entering the gypsum, sinking was continued with temporary timbering. As the water steadily increased, it was decided, in March, 1899, at a depth of 34 m. (111 ft.), to abandon hand-sinking and pumping and introduce the freezing method. This was deemed advisable in view of the excessive expense of pumping so large a volume of water, and the difficulty of disposing of a 4% brine, and also because it had become unpleasantly evident that the shaft was draining a considerable area of the surrounding country. The company decided to do the work on its own account, employing as its technical adviser the "Enterprise Générale de Fonçage de Puits," of Paris.

The freezing-pipes were sunk outside of the drop-shaft in a circle 9 m. (29.5 ft.) in diameter. There were thirty pipes in all, spaced 933 mm. (3 ft.) apart. It was planned to sink them to a depth of 128 m. (420 ft.), as it was assumed that the clay-bed between 90 and 120 m. (295 and 393 ft.) would cut off

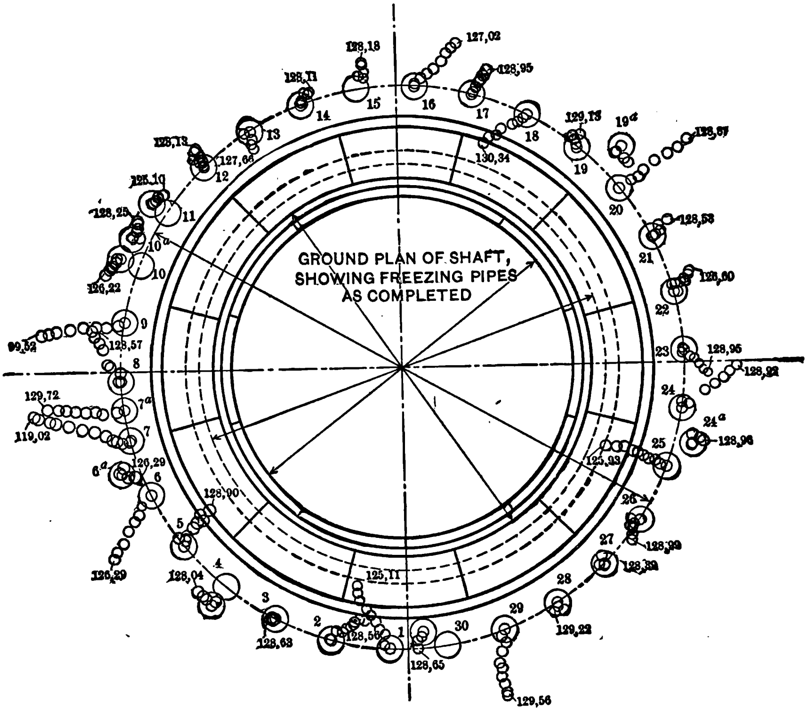

FIG. 13.—Plan of Bore-holes for Freezing-pipes, showing their deviations.

the water from both the gypsum occurring above 140 m. (459 ft.) and also the underlying rock-salt, and that the gypsum formation would consequently be dry. The freezing-pipes were 121 mm. (4.7 ins.) outside diameter. The refrigerating-plant was installed in duplicate, with a total hourly capacity of 240,000 calories at 25° C.

The sinking of the bore-holes for the freezing-pipes was let by contract, with the proviso that for each hole showing a greater deviation than 400 mm. (15.6 ins.) from the vertical another would have to be put down. This limit of deviation was afterward extended to 900 mm. (35 ins.), as advance in the work proved it to be sufficient to insure safety in freezing. It was erroneously assumed that from six to eight months would suffice for drilling the holes; unfortunately, nineteen months were found to be necessary, though in that time five extra holes were put down, making a total of thirty-five.

The holes averaged 127 m. (416 ft.) in depth, their total length therefore amounting to 4445 m. (14,580 ft.). The price was 60 marks per meter ($4.57 per ft.), or something more than 260,000 marks ($65,000) for all. For determining the verticality of the bore-holes, means were employed which it would take too long to detail in this place. The method was based on lowering by a wire a plumb-bob, which fitted quite closely in the hole, and then measuring the deviation from the vertical of the continuation of the wire above the surface. The small circles at each bore-hole, as shown in Fig. 13, indicate the results obtained. The five supplementary holes are designated by the same number as the adjacent original holes, with the addition of the letter *a*. It is evident that no hole was truly vertical, also that in some cases material deviations occurred. The subsequent sinking operations showed, moreover, that the method of testing employed was not very exact, as two freezing-pipes became visible in the sides of the shaft, a condition of things not shown by the holes as plotted according to survey. However, the success attained in sinking the shaft proved that such deviations as occurred are permissible when the refrigerating-plant is of ample capacity. Notwithstanding the

ultimate failure of the case under consideration, it is clear that the freezing process met all demands made on it, and the experience gained goes far toward extending the field of its applicability. The freezing-pipes were put in place immediately on the completion of each bore-hole, so that the casing could be pulled and used again in the next hole. The bore-holes were finished four weeks in advance of the rest of the connections and piping, and the machinery had been already installed and tested. The refrigerating-plant consisted of a duplex engine of 75 to 80 H.P., with a total capacity of 240,000 calories per hour. A 28% calcium-chloride solution was used. The water required for cooling purposes amounted to 40 cbm. (10,560 galls.) per twenty-four hours at 10° C., and was furnished by a special water-supply, as it was not deemed safe to withdraw water from the vicinity of the shaft for fear of causing movements of the ground at the shaft-collar.

On beginning the freezing the plant was operated to its full capacity, so that in seven to eight weeks the frozen wall was closed and already 2 m. (6.5 ft.) in thickness, as was learned by means of small test bore-holes. (It may be stated here that at the end of six months the ground was frozen solid to the center of the shaft, and to a distance of 3 m. (9.8 ft.) outside the circle of pipes.)

After twelve weeks it became evident from the rising of the water in the shaft that the cross-section below must be frozen solid and that the rising of the water was due to the progressive freezing from below upwards. Unwatering was begun, but continued somewhat intermittently. Careful observations, made in the intervals of pumping, demonstrated that there was but little leakage through the frozen ground, and the unwatering was successfully concluded by the early part of

May, 1901. The speed of advance in the clays and gypsum was slow on account of the caution necessary in blasting, which was done only in the middle of the cross-section, the sides being taken out with the pick. Dynamite was used in the more central holes, and black powder in others placed about 30 ctm. (12 ins.) from the walls. As sinking progressed, the temperature of the air dropped to $-8°$ C., so that ventilation was changed from suction to forced draft, which caused a minimum temperature of $-4°$ C.

The first wedging-crib, for cutting off the surface water, was placed in gypsum at a depth of 69 m. (226 ft.), and upon it tubbing-rings were built up to a point above the natural level of the ground-water. The original drop-shaft, which had been sunk to 27 m. (88 ft.) from the surface, was removed in the course of this work. A second wedging-crib was installed in hard impervious clay at 105 m. (344 ft.) and tubbing carried up from it to the crib above. The ground between these two horizons consisted of clay and gypsum, much broken by fissuring and cavities, which were filled with ice. The hard-pan found at 100 m. (328 ft.) changed at a depth of 110 m. (361 ft.) into a sandy material containing nodules of gypsum. As the bore-holes previously put down had led to the conclusion that this material would pass into hard gypsum at 125 m. (410 ft.), plans had been made for setting the last wedging-crib between 125 and 127 m. (416 ft.). At 125 m., however, water broke into and flooded the shaft before the crib and tubbing-rings could be put in place. This inflow was due to the presence of a concentrated solution of salt (25% of salt was ascertained by analysis), which had prevented the completion of the freezing at this point. The rate of advance in the frozen ground had varied from 16 to 24 m. (52 to 79 ft.) per month, and averaged,

including the placing of the tubbing, 12 to 14 m. (39 to 46 ft.) per month.

Although the idea is often held that, by employing a lower temperature, for which some agent other than chloride of lime would be necessary, even concentrated salt solutions may be successfully frozen, the Ronnenberg Company nevertheless decided, on account of the flooding of the shaft, to continue work by the Kind-Chaudron method. It is stated in the journal "Industrie" that this decision was based on the uniform success which in recent years has been secured through this process by Messrs. Haniel & Lueg.

For the time being and pending the installation of the equipment for boring, freezing was continued at the maximum capacity of the plant. The shaft was filled with gravel up to the wedging-crib at 105.4 m. (346 ft.), to protect the sides against the action of the salt solution which had broken in. In March, 1902, the shaft was unwatered down to the gravel, the mud removed, and sinking begun in the frozen gravel. On reaching the wedging-crib, the water again broke in, flowing this time $2\frac{1}{2}$ cbm. (660 galls.) per minute. The water was not very saline, containing some 4% of salt only, but had a temperature of 15° C., in spite of the fact that the freezing-plant was being run to its full capacity. At water-level in the shaft the temperature was 3° C. The consumption of coal at this time was 28 tons per 24 hours. Fig. 14 shows the condition of the sump when sinking was resumed.

During the last period of work one of the freezing-pipes had broken, so that 6 cbm. (1584 galls.) of calcium-chloride solution were lost. Toward the end of March, 1902, the freezing system was definitely abandoned and all energies bent to the Kind-Chaudron equipment, the successful operation of which

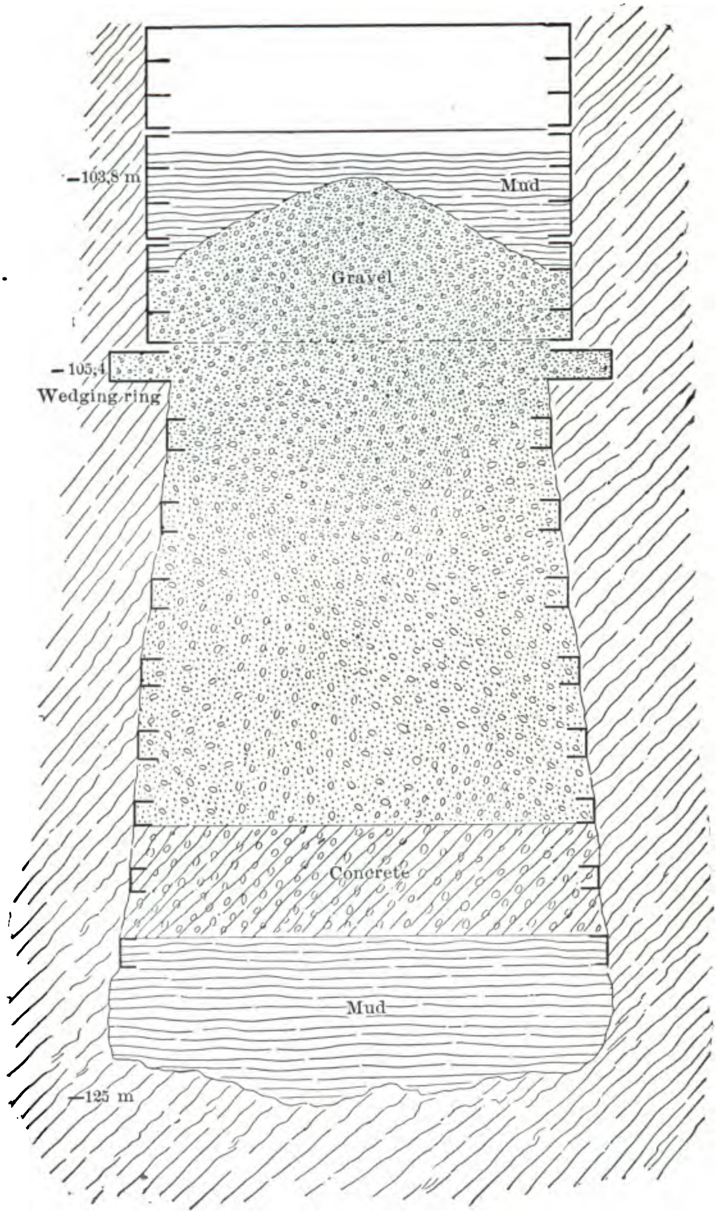

FIG. 14.

at this shaft has already been described in Part II of this volume.

THE SHAFT IN THE "GEMEINSCHAFT" FIELD OF THE "VEREINIGUNGS-GESELLSCHAFT", NEAR KOHLSCHEID IN THE WURM DISTRICT.

This shaft was started with a masonry drop-shaft, 6.7 m. (22 ft.) in the clear, which was put down to a depth of 18.5 m. (61 ft.). An iron drop-shaft 6 m. (19.7 ft.) in diameter was then sunk to 69.5 m. (228 ft.) and a second one 5 m. (16.4 ft.) in diameter to 102 m. (334 ft.). In spite of all efforts to force them deeper with jacks, both shafts stuck fast at these depths, and as both were more or less distorted, further attempts had to be abandoned. A third drop-shaft, also of iron and 4.3 m. (14.1 ft.) in the clear, stuck at 113 m. (371 ft.), although it was hoped to reach solid ground with it at 160 m. (525 ft.).

The formation passed through consists of a very fine-grained, round, and compact sand, which caused much trouble in its removal. Originally a dredge was used, but later, on proving no longer efficient, it was replaced by a sack-borer (see Fig. 16). This also made slow progress, so that a special sack-borer with removable bags was eventually installed, which caused much trouble because of lack of skilled men to operate it. One inburst of sand buried the borer 13 m. (43 ft.) deep so that neither it nor the rods could be raised to the surface. "Mammoth" pumps (using compressed air) were employed to clear the boring apparatus and proved very useful for this purpose, but were not so well suited for sinking, so that the sack-borer was again resorted to.

After the third drop-shaft had stuck at 113 m. (371 ft.) it was decided to let a contract to finish the work by the freezing process. As a preliminary a large circular excavation was made at the surface, in which the distributing piping was ultimately installed.

On February 26, 1902, boring was begun for putting down the 38 freezing-pipes. These were arranged in two circles, respectively 10.3 (34 ft.) and 11.3 m. (37 ft.) in diameter and sunk 10 m. (33 ft.) into the underlying solid rock.

On plumbing the bore-holes it was found that a number of them deviated considerably from the vertical, so that six additional holes were eventually put down. There were thus 44 in all, supplemented by a single hole in the center. In loose ground the pipes were sunk by a water-jet from a force-pump; in hard ground the usual form of drill was used in most cases, though core-drills were employed for eight of the holes, in order to obtain cross-sections of the ground traversed.

Part of the plumbing was done by means of a wire plumb-bob and part by a stratameter, neither method proving entirely reliable. The former becomes practically useless if the wire touches the walls of the pipe at any point; and the magnet of the stratameter is influenced by the iron casing of the bore-holes. Only the direction of the stratameter reading, however, and not the amount of deflection, is affected, so that the apparatus is a distinct improvement over the plumb-bob. A stratameter survey of each bore-hole was made for each 20 m. (65 ft.) of depth and a final observation taken at the bottom of each hole.

The original ice-plant consisted of an ammonia-machine, with cylinders 325 mm. (12.67 ins.) diameter by 600 mm. (23.4 ins.) stroke, run by a direct-connected, condensing steam-engine;

this was supplemented by a second ammonia machine, with two compressing cylinders, each 255 mm. (10 ins.) diameter by 450 mm. (17.5 ins.) stroke, driven by a belt from a condensing engine. The plant was put in operation April 1, 1903. As the capacity proved too small, an auxiliary refrigerating-engine of similar type, with cylinders 250 mm. by 450 mm. (9.75×17.55 ins.), was added in July, 1903. It was driven by a non-condensing engine and started August 8, 1903. The total capacity of the entire plant was 240,000 calories per hour. Although no material interruption occurred, progress was slow. On January 30, 1904, ten months after starting up, the downcast solution had a temperature of $-14.8°$ C. and the upcast $-9°$ C. An attempt was made on this date to unwater the shaft to a point 30.8 m. (101 ft.) below the collar, or 13.8 m. (45 ft.) below the normal ground-water level. It proved a failure, however, as the water rose 3.3 m. (11 ft.) during the following night. The shaft was promptly refilled with surface-water and freezing continued. Conditions then began to mend, so that by the middle of May the temperature of the down-cast solution was $-18°$ C. and of the up-cast $-12°$ C. Unwatering was then successfully accomplished. Sinking was begun in the latter part of May, fourteen months after starting the refrigerating plant. The 4.3-m. (14.1 ft.) drop-shaft was first removed; also the shoe of the 5-m. lining. The walls below the drop-shaft were lined as sinking progressed with suspended tubbing, 5 m. (16.4 ft.) clear diameter. The blasting was done with compressed powder and good progress made without mishap, the only unfavorable condition being that the shaft was solidly frozen to the center, due to the fact that the freezing had continued for a period of twenty-one months.

This proved a fortunate condition of affairs, however, as

many of the freezing-pipes had materially deviated from the vertical. In spite of the obstacle formed by the iron drop-shafts down to a depth of 112 m. (367 ft.), four of the freezing-pipes had protruded into the cross-section of the shaft. No. 27, for instance, showed 3.9 m. (13 ft.) of deviation between 127 m. and 154 m. (416 and 505 ft.) of depth, and at 154 m. was close to No. 13, whereas at the surface the two holes were 10.4 m. (34 ft.) apart. At 102 m. (334 ft.) No. 30*a* came into view, lying close to the iron walls of the 5-m. (16.4 ft.) drop-shaft. Below this point it was again deflected out of the cross-section of the shaft. These as well as other deviations proved that the bore-hole surveys with a stratameter are accurate as to amount of deflection, but are unreliable respecting the orientation of the deflections.

Judging from the above results it seems highly problematical whether the original plan, to enlarge the shaft to 6 m. (19.7 ft.) diameter, could have been successfully carried out by means of suspended tubbing, in spite of the fact that the frozen cylinder of ground had a diameter of between 10.3 and 11.3 m. (33.8 and 37 ft.).

Early in December, 1904, a depth of 154 m. (505 ft.) was attained, and the lining completed, with a water-tight joint in the solid carboniferous rock, thus successfully ending a very difficult piece of work.

It is natural that so successful a process as the freezing method of sinking should have attracted the attention of many inventors. A few suggestions may here be made, with reference to the fundamental features of the process; first, as to doing away with the use of a salt solution as a means of transporting the cold; and second, freezing the ground in short sections as the work advances, rather than as a single cylindrical

mass, solid from top to bottom. Both of these modes of procedure retard progress. The possibility of leakage of the solution because of defective freezing-pipes is one of the most serious contingencies to be feared, because any portion of the ground once saturated with the refrigerating solution cannot be frozen, and dangerous inrushes of the surrounding soil during the operation of sinking become inevitable.

All attempts to provide some kind of expansion-joint in the freezing-pipes, to avoid the difficulties incidental to the contraction caused by the cold solution, have proved unsuccessful. Up to the present time the only means of avoiding trouble from this source is to use the best material for the pipes, make them sufficiently heavy, and exercise the greatest care in putting them together. Projects to do away altogether with the freezing-solution, as well as the various attempts to utilize the cold produced by the vaporization of certain fluids in the pipes themselves, have thus far been unsatisfactory in practice.

Another difficulty inherent in the freezing process is the tendency of all bore-holes to deviate from their initial direction. This tendency increases with the depth of the hole, and to it are chiefly due the suggestions which have been advanced for freezing the shaft in sections. M. Unger has patented the idea of placing at the bottom of each section an iron casting, attached to the lowest tubbing-ring, and similar to the diaphragm or false bottom of the cuvelage used in connection with shaft-boring. In this casting there would be a number of perforations, properly spaced and provided with stuffing-boxes, through which the holes for the next lower series of freezing-pipes would be bored.

P. Grotenrath and H. Hillenblink have also received a patent covering sectional freezing. They propose placing

vertical channels or pipes either behind the tubbing of the upper part of the shaft, in the concrete backing, or else in the tubbing itself, to serve as guides for the future drilling of the holes or even as casings for the freezing-pipes. This plan has the advantage over the one previously mentioned in that each new circle of pipes would be larger instead of smaller than the first, so that the section of the shaft could be readily maintained of the original area.

The continually decreasing shaft cross-section is one of the worst features of sectionalized sinking by the freezing process. As the boring for each section of shaft must be done separately and a fresh freezing of that portion is required, costing both time and money, this method will scarcely prove more than a makeshift, to be adopted only when it cannot be avoided. Thus far the only improvements worthy of consideration are those bearing on the methods of freezing the entire depth and area of the shaft in one operation.

TABLE No. 2.—TABLE OF SHAFTS SUNK BY THE FREEZING PROCESS TO 1904.

No.	Country.	Place.	Name of Mine or Company.	No. of Shafts	Dimensions or Diameter.	When Sunk. Begun	When Sunk. Completed.	Total Depth of Shaft.	Thickness of Strata Traversed by Freezing Process.
					Meters			Meters	Meters
1	Germany	Schneidlingen.......	Grube Archibald.............	1	3.14×4.71	1883	1883	39.50	34–39.50
2		Laurahütte, O.-S.....	Grube Michalkowitz..........	1		1883		80.0	75–80
3		Hennersdorf........	Grube Emilie................	1	2.68	1884	1885	38.50	0–38.50
4			Ditto.......................	1	3.10×4.30	1885	1885	36.50	10–35.30
5		Königs-Wusterhausen	Grube Zentrum...............	1	4.00×2.35	1884	1885	32.00	6–32
6	Belgium	Haine St. Paul......	Houssu Colliery.............	1	4.00	1885	1887	77.60	53–77.60
7	Germany	Jessenitz..........	Kaliwerke Jessenitz, Mecklenburg	1	5.00	1886	1888	77.50	7–77.50
7a			Ditto (continuation of No. 7)....			1888	1890	190	125–150
8	U.S.A.	Iron Mountain......	Chapin Iron Mine, Shaft D......	1	4.72×5.03	1889	1890	30.48	0–30.48
9	Germany	Tarnowitz..........	Grube Georgenberg............	1	3.0×4.5	1890	1890	23.50	0–23.50
10	France	Pont à Vendin......	Cie. des Mines de Lens, Shaft No. 10......................	1	4.80	1891	1892	40	15.63–40
11			Ditto, Shaft No. 11 bis.........	1	3.68	1892	1892	41.75	0–41.75
12		Lens..............	Ditto, Shaft No. 1.............	1	3.64	1896	1897	85	0–86.00
13			Ditto, Shaft No. 5 bis..........	1	3.64	1896	1897	70	0–70
14			Cie. des Mines de Lens..........	1	4.80	1901	1902	94	0–94
15			Ditto,.......................	1	4.80	1902			0–90
16		Hénin Liétard.......	Cie. des Mines de Dourges, Shaft No. 3 bis..................	1	4.60	1892	1893	57.06	19–57.06
17			Ditto, Shaft No. 7.............	1	4.80	1894	1895	58.50	0–58.50
18			Ditto, Shaft No. 2 bis..........	1	5.00	1901	1901	64	0–64

REMARKS.—1. Coal-measures reached, but shaft subsequently abandoned.
2. Never completed.
3. Pump-shaft.
4. Elliptical hoisting-shaft.
5. Coal was reached, but shaft afterwards abandoned.
7, 7a. Flooded at 50 m. Work ultimately completed, by Haniel & Lueg with Kind-Chaudron system.
12. Wooden cuvelage was replaced by iron.
15. Still sinking.

NOTE.—One meter=3.28087 ft.

TABLE No. 2.—TABLE OF SHAFTS SUNK BY THE FREEZING PROCESS TO 1904—*Continued.*

No.	Country.	Place.	Name of Mine or Company.	No. of Shafts	Dimensions or Diameter.	When Sunk. Begun	When Sunk. Completed.	Total Depth of Shaft.	Thickness of Strata Traversed by Freezing Process.
					Meters			Meters	Meters
19	France	Harnes	Cie. des Mines de Courrières, Shaft No. 9	1	4.60	1893	1894	51	31.25–51
20		Billy-Montigny	Ditto, Shaft No. 10	1	4.70	1895	1896	58	0–58
21		Sallaumines	Ditto, Shaft No. 12	1	4.80	1901	1902	67	0–67
22			Ditto, Shaft No. 13	1		1902			
23		Raches	Ste Houillère de Flines-lez-Raches Shaft No. 1	1	4.20	1894	1895	75	0–75
24			Ditto, Shaft No. 2	1	4.20	1898	1899	90.55	0–90.55
25		Fontinettes	Schiffshebewerk	1	3.71	1894	1895	20	0–20
26		Vicq	Cie. des Mines d'Anzin	1	5.05	1893	1894	92.50	0–92.50
27			Ditto	1	3.65	1893	1894	92.50	0–92.50
28			Ditto, Ledoux shaft	1	5.00			90	0–90
29		Fléchinelle	Cie. des Mines de Ligny-lez-Aire, Shaft No. 1	1	3.80	1895	1896	89	0–89
30		Tirmande	Ditto, Shaft No. 2	1	4.00	1900	1901	92	0–92
31			Ditto, Shaft No. 2 bis	1	4.00	1900	1901	87	0–87
32	Austria	Brüx	Venus-Tiefbau, Hoisting-shaft	1	4.10	1895	1896	80	40–80
33			Ditto, Air-shaft	1		1896	1897	80	
34	France	Vermelle	Cie. des Mines de Béthune, Shaft No. 8	1	4.00	1897	1898	29.30	0–29.30
35			Cie. des Mines de Béthune	1	5.00	1901		80	0–80
36		Auboué	Ste. des Hauts-Fourneaux de Pont-à-Mousson	1	5.00	1897	1900	136.20	0–136.20

REMARKS.—22. Still sinking. 25. Wooden cuvelage replaced by iron.
35. Still sinking.

NOTE.—One meter=3.28087.

TABLE No. 2.—TABLE OF SHAFTS SUNK BY THE FREEZING PROCESS TO 1904—*Continued.*

No.	Country.	Place.	Name of Mine or Company.	No. of Shafts	Dimensions or Diameter.	When Sunk. Begun	When Sunk. Completed.	Total Depth of Shaft.	Thickness of Strata Traversed by Freezing Process.
					Meters			Meters	Meters
37	Belgium	Harchies	Société de Bernissart	1	3.50	1897	1901	235	0–235
38			Ditto	1	3.50	1897		235	0–235
39	France	Dechy	Cie. des Mines d'Aniche	1	5.00	1898	1899	89	0–89
40		St. René No. 2	Ditto	1	5.00	1899	1900	72	0–72
41		Dejardin	Ditto	1	5.00	1900	1901	82	0–82
42	Germany	Empelde	Gewerkschaft Hansa-Silberberg	1	4.50	1898		115	62–86
43		Ronnenberg	Alkaliwerke Ronnenberg	1	5.50	1899	1901	135	34–125
44		Güsten	Herzogl. Anhalt, Salzwerksdirektion Leopoldshall	1	5.50	1899	1901	101.60	0–101.60
45–46	Holland	Heerlen	Soc. Anon. des Charbonnages Willem et Sophia	2	4.00	1899	1900	70	6–70
47			Soc. Anon. des Charbonnages Vereinigung et Laura	1					85–108.5
48	France	Lourches	Cie. des Mines de Douchy, Ste. Barbe shaft	1	5.00	1899	1900	47	0–47
49	Germany	Atzendorf	Konsol. Braunkohlenbergwerk "Marie"	1		1900	1901	60	50–60
50		Wolmirsleben	Gewerkschaft Konsol. "Sophie"	1	5.00	1900	1901	77.50	3–77.50
51		Mariadorf, near Aix-la-Chapelle	Vereinigungsgesellschaft, Wurm district	1	4.50	1899	1900	63	30–63
52	France	Crespin	Cie. des Mines de Crespin	1	5.50	1900		106	0–106

REMARKS.—38. Still sinking.
42. Still sinking.
43. Completed by the Haniel & Lueg system of shaft-boring.
48. Shaft enlarged from 2 m. to 5 m. diameter.

NOTE.—One meter = 3.28087 ft.

TABLE No. 2.—TABLE OF SHAFTS SUNK BY THE FREEZING PROCESS TO 1904—*Concluded.*

No.	Country.	Place.	Name of Mine or Company.	No. of Shafts	Dimensions or Diameter.	When Sunk. Begun	When Sunk. Completed.	Total Depth of Shaft.	Thickness of Strata Traversed by Freezing Process.
					Meters			Meters	Meters
53–54	England	Washington	Washington Colliery Co., County Durham	1	4.20	1901		33	0–33
				1	4.20	1901		160	0–160
55–56	Germany	Recklinghaus	Gewerkschaft Auguste Viktoria	2	5.50	1901		120	40–120
57		Duffesheide, near Aix-la-Chapelle	Vereinigungsgesellschaft, Wurm district	1	5.00	1901		160	113–160
58	France	Bruay	Cie. des Mines de Bruay	1	4.50	1902		95	0–95
59		Calonne Ricouart	Cie. des Mines de Marles	1	5.50	1902		115	0–115
60–61	Germany	Hakeborn	Konsol. Alkaliwerke Westergeln	2	4.50 / 5.00	1900		60 / 85	8–60 / 8–85
62		Frintrop	Arenbergsche Bergb.-Aktiengesellschaft in Essen	1	4.50	1902		20	0–20
63	Holland	Heerlen	Koninklijke Staatsmynwerken	2					
64	Germany	Sarstedt	Gewerkschaft Schieferkaute	1	4.70	1904		200	0–200

REMARKS.—55-56. One shaft completed; the other still sinking. 57. Started with a drop-shaft. 62. Still sinking. 63. Still sinking. 64. Still sinking.

NOTE.—One meter=3.28087 ft.

IV.

DROP-SHAFTS.

For sinking in sand or loose water-bearing soils the drop-shaft method is one of the oldest in use, if we except ordinary hand-work and spiling, which is now rarely employed under these conditions.

The method originally consisted in erecting a strongly-framed rectangular wooden casing on the spot where the shaft was to be sunk and, while excavating the soil within the inclosure, allowing the casing or lining to sink slowly into the ground. The function of the lining is to support the walls of the excavation and prevent them from caving. If water or running soil is encountered in such quantity as to drown out the work, excavation is necessarily carried on with appliances adapted to operate under water. At first, spoon- or pod-augers and sack-borers were employed; replaced later by chain-bucket dredges, claw or clam-shell dredges, and water-jetting apparatus. The early rectangular wooden casing was succeeded by a circular walling of masonry, first with a wooden, afterward with an iron, shoe. This in turn was superseded by a plate-iron cylindrical lining, and later by cast-iron tubbing, with machined joints.

Drop-shafts were first sunk by their own weight; later on this was supplemented by loading them with earth, sand, stone, iron, and eventually by the use of jack-screws and hydraulic jacks. In the modern development of the method

a large number of hydraulic jacks are connected by a system of piping with an accumulator, weighted for exerting automatically a constant pressure on the drop-shaft.

Recently drop-shafts have been greatly increased in diameter, and used for greater and greater depths, so that it has become necessary largely to increase the thickness of the iron walls. Notwithstanding this, shafts are often seriously deformed before reaching their final position. In the case of drop-shafts sunk through concrete plugs placed in the bottom, any injury appearing in the shaft might be attributed to the presence of the hard concrete. But other causes produce the same results, as may be inferred from the fact that drop-shafts which have had no concrete to pass through are frequently damaged. It is therefore evident that other and more general causes may be responsible for such deformations. These questions I will now proceed to discuss.

Of all the drop-shafts I have seen, only two wholly escaped deformation. All of the others had suffered more or less, either in a distortion of cross-section or by longitudinal rupturing. This statement holds good for both iron and masonry shafts. Horizontal cracks, girdling the shaft, are rare and occur only when the bottom of the masonry walling breaks off and sinks as quicksand fills the shaft, while the upper portion is held firmly by the frictional support of the overlying strata. Hugo No. 1 shaft, of the Gutehoffnungshütte, which was put down with a single drop-shaft between the depths of 61 and 170 m. (200 and 557 ft.), i.e., 109 m. (357 ft.), was finally completely wrecked by such breaks, although the walls were 70 mm. (2¾ ins.) in thickness.

In the case of a certain small iron drop-shaft, 4.5 m. (14.7 ft.) in diameter by 31 m. (102 ft.) deep, which was lost

in a similar manner, I was called in to give expert testimony, and so had to investigate the causes of the trouble. Close inquiry led to the conclusion that movements in the surrounding ground must have taken place, which were due to the operations incident upon sinking the shaft. The unstable ground was sandy, loose and clean layers alternating with others mixed with clay. Several inrushes of this material occurred during the progres of the work.

The cause of such movements is not difficult to understand. When the bottom of the shaft is in loose sand and the excavation has been carried down to, or perhaps below, the lower edge of the shoe, the unstable material outside must inevitably run in under the shoe. These movements are fostered by differences in specific gravity; the shaft being filled with water, with a specific gravity of 1, while outside the shaft-lining the unstable, water-bearing soil probably has a specific gravity of about 2. The pressure outside would therefore be twice as great as that within, were it not for the fact that a part of the difference is offset by friction.

When under these conditions a drop-shaft sticks, there is a great temptation to endeavor to start it by continuing excavation at the bottom and even undercutting the shoe, thus naturally increasing the tendency to an inrush of the surrounding ground. By the recurrence of such movements the cavities behind the shaft walls gradually grow larger upward and outward, and fill with water instead of sand. This continues until the openings as they extend upward reach a firmer stratum, when for a while, at least, no movement may be noticed. Fig. 15 shows a drop-shaft under the conditions described.

Finally a catastrophe is usually brought about by a sudden

breaking away of portions of the roof of such cavities. Masses of water and sand are violently forced up through the shaft bottom, subjecting the walls to very serious and damaging strains. The caving often progresses upward, until even the surface equipment of the shaft is endangered.

As a rule, the shock of the ground falling against the walls of the shaft is noiseless, as it takes place under water and the material has but little cohesion. Nothing may be noticeable at the shaft-collar except a sudden rise of the water-level, produced by the inrush at the bottom. It is impossible to estimate the force of the shock of such falling masses of ground, because, in the nature of things, the data can only be assumed, and the laws governing the movement of soft, unstable material in water are completely unknown.

At best, therefore, a rough calculation only can be made. Take, for example, a case where the radial width of the water-filled cavity is supposedly 4 m. (13 ft.), the height 10 m. (33 ft.), and where the roof has dropped around one quarter of the circumference, which is, say, 24 m. (79 ft.). If the thickness of the caved ground be 5 m. (16 ft.), a mass of material measuring $4 \times 6 \times 5$ m. $= 120$ cbm. (157 cu. yds.) would come down. Adopting the specific gravities previously instanced, there would be a net weight unsupported by the water, of 120,000 kg. (264,000 lbs.). Furthermore, assuming the time of drop in water to occupy two seconds, the energy developed would amount to

$$\frac{120{,}000 \times 10}{2 \times 75} = \frac{(120{,}000 \times 2.2) \times (10 \times 3.28 \times \frac{60}{2})}{33{,}000} = 8000 \text{ H.P.}$$

This of course is a mere estimate, a large part of the shock is absorbed by the slope of the bottom of the cavity and the falling material is not compact, so that only a fraction of

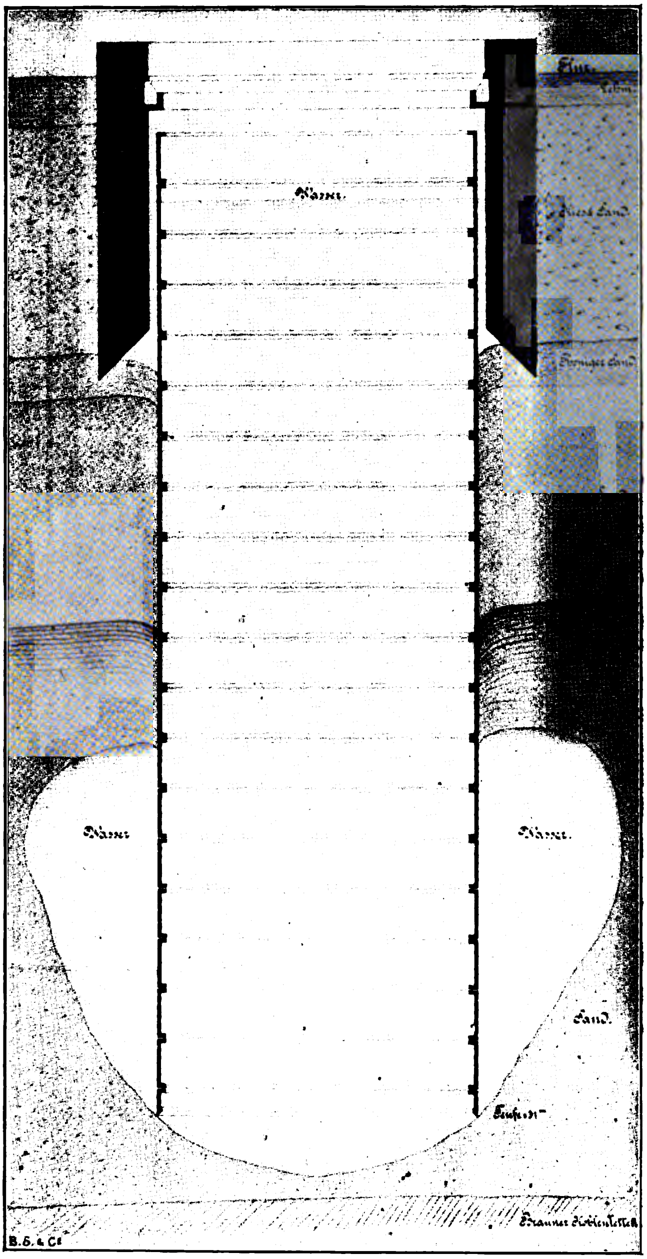

FIG. 15.

the above energy is actually exerted against the walls of the shaft. Nevertheless there is still sufficient force, under the conditions set forth, to furnish an impressive idea of the possible strain on the shaft-walls. A further indication of the large forces involved in such occurences is found in the fact that the bottom of the shaft and the water level often rise suddenly many meters. I know of one case in which the rise was 22 m. (72 ft.), and of another, where the water-level was low, in which the compression of the air above it drove the shaft scaffolding to the surface, injuring a number of the men.

With these facts in mind, it is not surprising that, in spite of the increased thickness of the walls (90 mm. or 3.5 ins. having been already employed), drop-shafts are frequently damaged, particularly as the constantly increasing diameter of the shafts tends to nullify the advantages gained by increased thickness. Any further increase in thickness seems inadvisable, partly on account of the expense and partly because of the unwieldiness and the difficulty of handling the individual segments in the shaft. Replacing cast-iron by cast-steel would treble the cost without corresponding advantage, because the relative strength of the metal is the main question, and for this kind of work cast-steel is not much superior to cast-iron. The main point is to avoid sudden inrushes of soft material, and these are best prevented by keeping the cutting edge of the shoe always in unbroken ground, i.e., well ahead of the actual bottom of the shaft. This can be done only by using powerful jacks to force down the lining.

Unfortunately in sinking drop-shafts there are no sure means of ascertaining how much ground has been removed. It is always uncertain, therefore, whether cavities may have formed behind the shaft walls, as there is no safe guide as to the

ratio of the ground in place to that which is hoisted to the surface. By exercising care and employing powerful hydraulic jacks for keeping the shoe well ahead of the bottom of the shaft, the danger can be much reduced but never completely eliminated.

For these reasons persistent attempts have been made to increase the strength of drop-shafts. But the preceding remarks as to the thickness of walls and the available materials indicate that such increase of strength is to be secured only by improved construction, at the same time avoiding, if possible, any increase in weight.

At the suggestion of Manager Pattberg, a composite drop-shaft of iron and masonry or concrete was patented in Germany by Haniel & Lueg under Patent No. 133,482. Its essential feature is the interpolation of broad, stiff reinforcing-rings, set between the tubbing-rings. These are intended to prevent deformation of the shaft by lateral crushing. In the lower portion of the shaft, where the pressure is greatest, the rings are placed quite close together, say every 3 m. (10 ft.); above they are spaced from 4 to 5 (13 to 16.5 ft.) or even 6 to 9 m. (20 to 30 ft.) apart. Broad rings of this kind, though necessarily projecting somewhat on the inside of the shaft, beyond the flanges of the tubbing, materially stiffen the structure. They are tied together by heavy bolts, and the spaces between them filled with concrete or masonry, so that the inner surface of the shaft is entirely smooth. The masonry adds to the stiffness of the shaft, and at the same time furnishes an advantageous increase in weight.

The walls of such shafts are naturally thicker than those of an ordinary iron drop-shaft: being, in this respect, intermediate between iron and solid masonry. This is an unfavorable feature, particularly when with increasing depth the telescoping

of several successive linings becomes necessary. The disadvantage, however, is in a measure offset by the fact, as shown by experience, that such shafts can be carried deeper than the ordinary unlined iron ones. This construction was adopted at shafts Nos. 4 and 5 of the Rheinpreussen colliery, as shown on Plates XVI and XVII. Further details will be given below when the sinking of these shafts is described.

General Superintendent Hinselmann, of Rheinpreussen, has patented an interesting innovation in connection with sinking by drop-shafts. He suggests a composite drop-shaft, whose shoe has a broad outside flange projecting beyond the walls. Upon this broad outer flange a sufficient number of concentric cast-iron tubbing-rings would be placed to serve for the entire depth to be sunk. These auxiliary rings should fit over one another and over the main drop-shaft with a small amount of play. The whole would constitute a very heavy drop-shaft, with a number of loose outside casings. It is planned to leave open vertical channels in the thick walls of the main drop-shaft, in which freezing-pipes may be placed in case it should become necessary ultimately to resort to the freezing process for completing the work. Operations are conducted as follows: The whole shaft, with its outside casing-rings, is sunk until the friction on the outermost ring becomes so great that it will go no farther, even with the aid of hydraulic jacks. Then the jacks are applied to the second ring, the first remaining stationary, while the main drop-shaft, with the other rings, being relieved of part of the outside friction, sinks farther. This method of procedure is applied to each succeeding outside casing-ring, until all have become stationary, when the pressure from the jacks is finally applied directly to the drop-shaft itself. This device has not as yet been applied in practice.

Coincident with the various improvements in the construction of drop-shafts, advances have been made in the methods of removing the material as excavated. These are the more important, as experience shows that by means of hydraulic jacks almost any desired speed of sinking may be attained. Theoretically, the rate of progress is limited only by the speed with which the lining-rings can be installed. With proper equipment three rings can be placed per twenty-four hours, equal to 4.5 m. (14.7 ft.) of depth. Such progress can be expected as soon as it becomes possible to carry on the excavation with corresponding speed. In spite of substantial progress, however, the methods in use for this branch of the work are still greatly in need of improvement.

As to the various methods of excavation which depend on the use of the old sack-borer, the claw-dredges, bucket-elevators, and pumps operated by water, air, or steam, details may here be omitted concerning the dredges and bucket-elevators, because no improvements in them, to my knowledge, have recently been made.

The sack-borer is much used when other methods fail, because although slow it is relatively sure in operation, and is adapted to all of the various kinds of ground likely to occur. It has been greatly improved by Sassenberg and Clermont. The inefficiency of the old form is chiefly due to the necessity of breaking joint throughout the entire length of rods whenever the sacks are to be raised and emptied. This is a slow and tedious process and greatly reduces the capacity of the apparatus.

Sassenberg and Clermont modified the sack-borer so that the sacks can be raised to the surface by a hoisting-engine, without raising and disconnecting the rods. For deep shafts

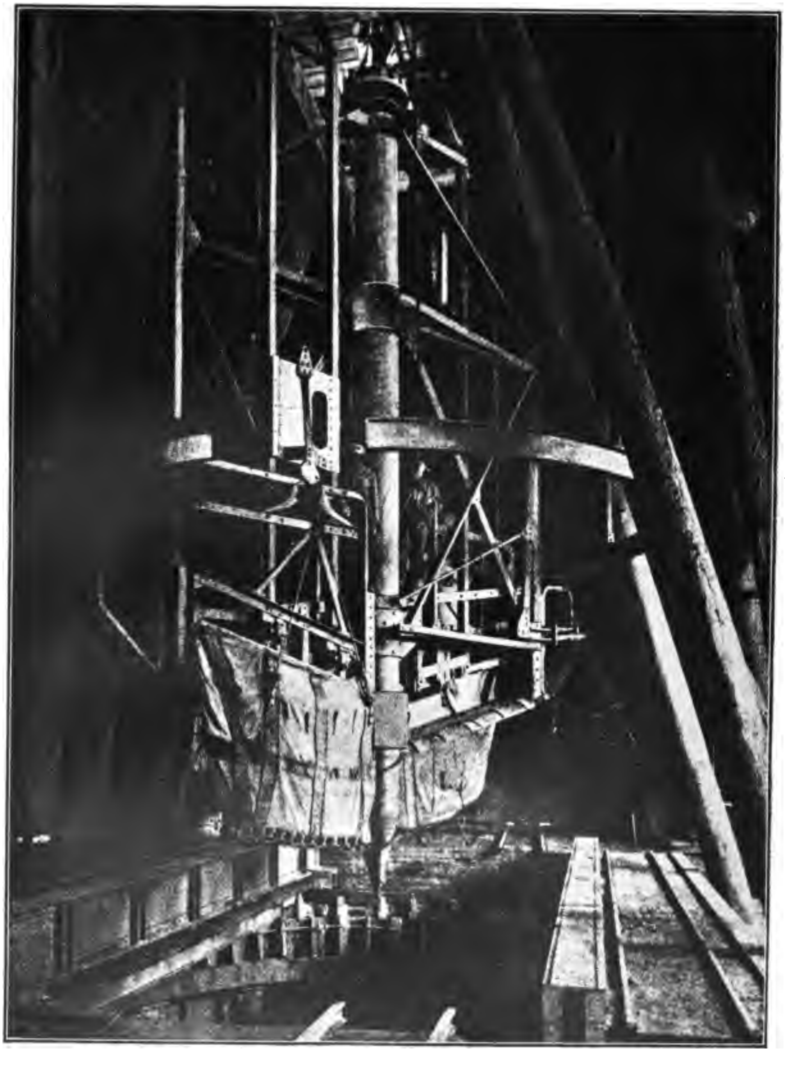

Fig. 16.—Sack-borer.

this makes it possible, under ordinary conditions, to raise and empty the sacks in as many minutes as it formerly took hours. The new design is shown on Plate XVIII, which represents the sinking-plant of the Adolf shaft of the Eschweiler Bergwerks-verein; and Fig. 16 is a reproduction of a photograph of the same apparatus, which bears Patent No. 96,015 of the German Empire. This equipment was also used successfully at Kohl-scheid and at the Adolf shaft near Alsdorf.

In connection with shaft-sinking, pumps for elevating the water and mud (this section of our subject deals only with sinking under water) have been more and more widely applied. Injection-pumps operated by water or steam, and the so-called "Mammoth" or air-lift pump, are most frequently used. The latter consists essentially of a large open pipe, with no valves, which is lowered to some depth into the water to be raised; into the lower end of this pipe compressed air is discharged from another smaller pipe, connected with a compressor. The air, rising in bubbles and disseminated through the liquid in the large pipe, makes a mixture of lower specific gravity than water alone. A constant discharge is thus maintained, assisted in a measure by the pressure of the water in which the pipe is immersed and by the kinetic energy and expansive force of the compressed air. This is an excellent means of raising water mixed with mud, sand, or gravel, as there are no moving parts subject to damage or derangement. The method is not new, having been first proposed, I believe, by W. Siemens. Borsig, of Berlin, has brought out several designs, and F. Honigmann, of Aix-la-Chapelle, has patented a device in which the boring-rods themselves are utilized as the pump column. The recent installation of the apparatus at the Rheinpreussen shafts Nos. 4 and 5 is shown on Plates XVI and XVII.

The tendency of drop-shafts to diverge from the vertical is a serious matter, and to allow for the consequent reduction in working cross-section careful consideration is required when deciding on the initial diameter of the shaft. This difficulty may to a certain extent be overcome, when hydraulic jacks are used, by providing rigid guides between the heavy anchor-rings of the jacks (German patent No. 91,572), as shown on Plates XVI and XVII. It is exceedingly important to eliminate as far as possible any chance of deviation, the principal cause of which is probably to be found in the tendency of all rotating borers, in which class the sack-borer belongs, to "run off", or depart from their true direction. Claw-dredges and the usual methods of suction dredging offer no better security for the maintenance of true verticality, and of course the drop-shaft will naturally follow the excavation, even when inclined in direction, so far as its guides will permit it so to do.

These considerations led Manager Pattberg, of Rhein-preussen, to design a drop-drill. The ground is broken by a trepan, so arranged that water under pressure can be delivered at the cutting edge, through the hollow drill-rods. The water-jets are directed upon the bottom of the shaft, stirring up and carrying away the debris. The trepan is so shaped that the shaft bottom has the form of an inverted cone. At the lowest point two Mammoth pumps (Plates XVI and XVII), which are attached to the outside of the drill-rods, pick up the drillings and raise them to the surface. At the shaft-mouth an ingenious swivel-head admits the compressed air and pressure-water to the drill-rods and pumps.

The trepan is operated through a rope by an engine with an oscillating drum (German patent No. 104,158), equipped with a pneumatic feed-regulator (patent No. 105,931), the

flat rope running over a sheave at the top of the derrick and fastened to the swivel-head before mentioned. Thus the entire boring-apparatus is suspended by the rope from the drum, and while making its up-and-down strokes can be gradually lowered as the sinking advances. The plant as a whole is patented under No. 124,052, and is illustrated on Plates XVI and XVII. The engine only is shown in Fig. 17.

Honigmann's system of shaft-boring belongs to the same category, but cannot be described here, as too few details have as yet been published. In reply to inquiries concerning the process, Mr. F. Honigmann states that in the Orange-Nassau mining district, at Limburg near Heerlen, two shafts of 3.3 and 2.8 m. (10.8 and 9.2 ft.) diameter have been successfully put down to a depth of 97 m. (318 ft.) and lined with wrought-iron casing. He laso states that in the Carl district at Limburg two shafts of 3.9 m. (12.8 ft.) diameter have been bored to a depth of 130 m. (426 ft.), and lined with steel-plate cylinders from 15 to 20 mm. (0.58 to 0.78 in.) in thickness, reinforced by channel-irons. A similar shaft, 5.7 m. (18.7 ft.) diameter, has been sunk at the Nordstern Mine, near Aix-la-Chapelle, to a depth of 77 m. (252 ft.) and also lined with steel plate.

Of the more important work done with drop-shafts, hydraulic jacks, and guides under patent No. 91,572, the following may be described:

1. The Hugo Shaft at Holten, Gutehoffnungshütte Mining District.

Work was begun by putting down a masonry drop-shaft, 7.2 m. (13.6 ft.) in the clear, to a depth of 20 m. (65 ft.) below ground-water level, and continued with suspended tubbing, 6.72 m. (22 ft.) inside diameter, to a depth of 80 m. (262 ft.).

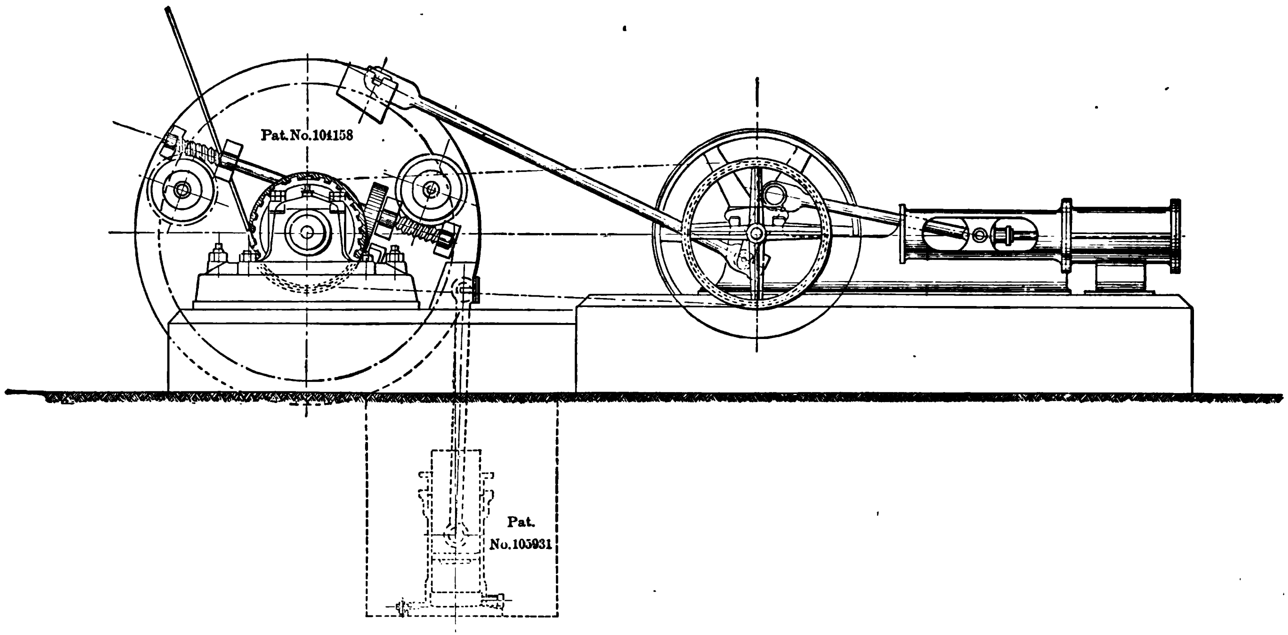

FIG. 17.—Percussion Boring-engine, with Pneumatic Feed-regulator, Designed by Pattberg.

The bottom was then concreted up to 65 m. (213 ft.) below the surface and an iron drop-shaft installed, 6.08 m. (19.94 ft.) in the clear. This lining was forced down to 175 m. (574 ft.), i.e., a depth of 110 m. (361 ft.) after which another concrete bottom was put in and the shaft pumped out. The lining proved to be out of shape and damaged, and the shaft was ultimately ruined completely by crushing of the walls.

2. The Sterkrade Shaft, at Sterkrade, in the Same District.

Like the Hugo shaft above mentioned, this was also started with a drop-shaft 7.2 m. (13.6 ft.) inside diameter, which was sunk by pneumatic jacks to a depth of 17 m. (56 ft.). Sinking was continued by hand and masonry lining put in, in sections, down to 40 m. (131 ft.). This was followed by an iron drop-shaft, 6.72 m. (22 ft.) net diameter, to a depth of 80 m. (262 ft.), where the lining stuck fast. A second iron drop-shaft, 5.9 m. (19.35 ft.) diameter, was forced down to 132 m. (433 ft.), where the water was shut out in the clay formation. After the unfortunate experience at the Hugo shaft, it was considered advisable to put in still another drop-shaft 5.1 m. (16.73 ft.) in the clear. This, too, stuck fast at a depth of 136.5 m. (448 ft.), but the ground proved favorable for making a water-tight connection, and sinking being resumed by hand, a final iron lining was put in above the 140-m. (459 ft.) horizon, with masonry below that level.

3. Hugo Shaft No. 2, in the Same District.

This was sunk to replace shaft No. 1, which had collapsed. The method of sinking was much the same, except that, as in the case of the Sterkrade shaft, masonry was used instead of

suspended tubbing. The masonry drop-shaft was 7.2 m. (23.6 ft.) in the clear and was lowered under water 20 m. (66 ft.). Sinking was then prosecuted by hand and continued with masonry walling to a depth of 70 m. (230 ft.). The sump was concreted to the 61-m. (200 ft.) level and an iron drop-shaft installed 5.8 m. (19 ft.) in diameter. By the end of July this had reached a depth of 162.5 m. (533 ft.), and there stuck fast. The lining was probably water-tight, but in order to avoid unnecessary risk at so great a depth, a section of lining of smaller diameter was inserted at the bottom. This could not be forced below 167 m. (548 ft.), at which point hand-sinking was resumed.

In all these shafts the ground broken was removed by the claw-dredge, which worked well in the material traversed. A trepan designed by Director Jacobi for the harder layers, which was held in reserve, was not found necessary.

The suggestion of Director Kocks to use a Kind-Chaudron trepan to break through the concrete plug in the shaft-bottom was applied in these cases for the first time and was entirely successful, the steel drop-shaft shoe cutting away without difficulty the narrow annular shelf of concrete remaining. The hand-work necessary in cutting through the bottom of the bed of concrete, which in shafts of great depth and diameter is often perilous, is by this means reduced to a minimum.

4. The Adolf Shaft of the Eschweiler Bergwerks-Verein, near Alsdorf. (Plates XVIII and XIX.)

At the point chosen for starting the shaft the ground-water level was 32½ m. (107 ft.) below the surface. The upper part of the formation is of gravel, underlaid by sandy and clayey strata. Solid ground occurs at a depth of 140 m. (459 ft.).

Sinking was begun and carried down to water-level with a

shaft of large diameter, lined with heavy masonry walling, 1 m. (3.28 ft.) thick and 7.7 m. (25.25 ft.) diameter in the clear, carried to a depth of 32 m. (105 ft.). This walling was utilized as foundation and loading for the pressure-ring of the hydraulic jacks, according to Patent No. 91,572. Lying within the walling and serving at the same time as guides for the iron-drop-shaft, are 14 anchor-bolts, each 100 mm. (3.9 ins.) square. The lower ring for these anchor-bolts was placed near the bottom of the masonry, 30 m. (98 ft.) below the pressure-ring. There are 14 hydraulic jacks, each of 150 tons capacity; a total of 2100 tons. The first iron drop-shaft, 7.1 m. (23.3 ft.) in the clear, consists of 14-segment rings, 1.5 m. (4.9 ft.) high, which in the lower 33 m. (108 ft.) of the shaft are 80 mm. (3.1 ins.) in thickness.

The sinking of the drop-shaft was started early in December, 1900, by putting in the shoe at a depth of 32.5 m. (107 ft.), and progressed well up to January 21, 1901, when, at 43.26 m. (142 ft.), three of the heavy anchor-bolts broke. In order to make repairs it became necessary to remove the iron drop-shaft, causing over three months' loss of time. The breakage being due to defective material in the bolts, it was decided to supplement the 14 original bolts by 28 others, each 60 mm. (2.35 ins.) square.

Sinking was resumed April 30, 1901, and progressed so well that by June 15th the shoe of the drop-shaft was at 55.21 m. (181 ft.) below the surface. Then a delay occurred for installing gearing on the hoist used for raising the sacks of the sack-borer. Sinking was continued July 16, 1901, but on August 8, 1901, at 61.57 m. (202 ft.), an inrush of soft ground took place under the shoe and filled the bottom to a depth of 4 m. (13 ft.). The source of the trouble was not overcome until October 1,

1901, when the sinking again proceeded, and the shoe was eventually lowered to 76.72 m. (252 ft.), where it stuck fast November 13, 1901. The drop-shaft itself weighed at this time 1200 tons and was finally loaded with 2400 tons more. Further attempts to lower the shaft by undercutting at the shoe were abandoned, and a concrete plug was put in the bottom on which to build up the second iron drop-shaft, provision for which had been made at the beginning. Exclusive of various interruptions which had nothing to do with the sinking, the progress made thus far was good, due primarily to the arrangement of the jacks, but also to the use of the sack-borer with detachable sacks.

The second iron drop-shaft, begun early in October, 1902, was of 6.4. (21 ft.) diameter and in its lower portion 90 mm. (3.5 ins.) thick. It had a heavy cast-steel shoe with steel bands, and in connection with it there was put in use for the first time a novel device patented under No. 136,672 by Bergverwalter Sassenberg. This will be understood from the following:

In sinking Hugo shafts Nos. 1 and 2 and the Sterkrade shaft of the Gutehoffnungshütte, at Holten and Sterkrade, attention had been repeatedly attracted to the great depths reached with a single drop-shaft lining. All three shafts reached depths of 90 to 110 m. (295 to 361 ft.) with the first drop-shaft, and those who were in full possession of the facts were of unanimous opinion that this success was entirely due to the favorable geological conditions. At a depth of 110 m. in that district there is a water-bearing layer where the pressure is so considerable that when a shaft reached it the water rose to the surface outside of the shaft-lining and there flowed away. This flow continued during the entire subsequent progress of sinking, forming a small stream of 80 to 100 l. (21 to 26 galls.)

per minute. Such an upward flow between the shaft-lining and the ground outside tended greatly to reduce friction. The water was prevented from entering the shaft by a clayey layer immediately under the water-bearing strata, which was cut into by the shoe of the shaft, thus forming a water-tight joint.

Sassenberg conceived the idea of reproducing artificially these favorable natural conditions by providing an annular channel in the tubbing, somewhat above the shoe, this channel containing a number of small holes through which water under pressure could be forced out into the surrounding ground. For this purpose the shoe and the four bottom rings were made 40 mm. (1.56 in.) larger in outside diameter than the rest of the tubbing, and the holes for the outflow of the water were distributed around the 20-mm. (0.78 in.) shoulder thus formed, at about 7 m. (23 ft.) above the shoe. This enlargement of the lower part of the shaft was intended, first, to exclude the ground-water from the shaft, and, secondly, to facilitate the upward flow of the water ejected from the openings on the 20-mm. shoulder. It was intended that the enlarged portion of the lining should fit so closely in sinking through the strata as to act as a sort of packing in preventing the water from passing downward under the shoe into the shaft. To make this doubly sure the entire enlarged section of lining was turned smooth and true before installing. The pressure water was conducted to the annular channel through vertical channels cast in the tubbing-rings above the shoulder, and above these, in turn, through pipes leading from the surface and fastened to the inner walls of the lining. Two small pumps supplied all the water required. The details are shown on Plate XIX.

In October, 1902, drilling through the concrete plug was begun. The same sack-borer was used which had been employed for sinking, but altered so that its cutting edges were replaced by two spindles carried in inclined bearings and provided with rotating cutting-disks. After a few minor delays the 14 m. (46 ft.) of concrete were cut through and followed by the drop-shaft by the end of March, 1903. The next strata were clayey and the sack-borer was again brought into use, but was not very efficient until the cutting edges had been adapted to the material traversed. At 82.52 m. (271 ft.) the pressure water apparatus described above was put in operation, and an attempt made to raise the level of the water behind the second drop-shaft to a drainage-channel 7 m. (23 ft.) below surface, i.e., about 25 m. (82 ft.) above the natural water-level, which was at a depth of 32 m. below the surface. As soon as the water between the iron drop-shafts reached a point 11–12 m. (36–39 ft.) below the drainage -channel, the second drop-shaft commenced to sink, although before that time it had failed to respond to a pressure of 3000 tons. In order to control the movement a Mammoth pump was lowered between the walls of the two drop-shafts and the water-level maintained at a point 10 m. (33 ft.) above the ground-water. The water pumped out flowed into the storage-tank for the pressure-pumps and was thus used repeatedly. The drop-shaft sank by its own weight, the jacks therefore being no longer necessary. The use of the pressure water was eminently successful, so that in June, 1903, no interruptions having occurred, an advance of 18.21 m. (60 ft.) was made, the shoe reaching a total depth of 100.73 m. (330 ft.).

On September 25, 1903, at a depth of 129.9 m. (426 ft.), the sack-borer brought up a piece of tubbing-flange. The borer

was raised and investigations made with a claw-dredge. As a result several more pieces of iron were found, indicating some material damage to the lower portion of the shaft-lining and the impossibility of sinking it any further. Although the last 25 m. (82 ft.) of shaft had been in fairly hard clay, unwatering was delayed in order to ascertain the extent of the damage and whether it would be feasible to continue the work by hand.

The shaft was therefore filled with sand to within 80 m. (262 ft.) of the surface and an attempt made to pump in liquid cement through the perforated circular channel provided for the pressure water, in the hope that it might fill all open spaces in the clay and so prevent further injury to the lining. Also, two bore-holes were put down through the concrete in the annular space between the two drop-shafts. Through these holes cement was pumped until it rose above the ring of concrete left between the two drop-shafts; that is, at the bottom of the first iron drop-shaft. After the cement had hardened, the shaft was unwatered and the work of removing the sand begun. At 88 m. (289 ft.) the flow of water was 6 l. (1.6 galls.) per minute. At 87 m. (285 ft.) more cement grouting had been injected until it again rose in the annular space above the concrete plug.

The first damage was noted at 97 m. (318 ft.), in a segment of the twenty-second ring above the shoe. This was on the westerly side of the shaft, the circular cross-section having been deformed into an oval, with a difference between the two diameters of 380 mm. (14.8 ins.). The damage was identical with that already described in another case, and the vertical crack on the west side was followed by a similar one on the east. To prevent further crushing, a set of inside tubbing-rings, 5.73 m. (18.8 ft.) clear diameter and 50 mm. (1.95 in.) thick, was in-

serted, the space between the two linings being carefully filled with concrete. Five of these new rings were put in, from 105.75 m. up to 96.75 m. (347 to 317 ft.) below the surface. They were provided with outside cement ribs, projecting 15 mm. (0.58 in.), and concrete was carefully compacted behind them, to secure a reliable junction with the drop-shaft. The sand in the shaft was then removed in 1½-m. (4.9 ft.) sections, an additional tubbing-ring being bolted each time underneath the inner set and the space behind it filled with grouting through openings left for that purpose.

Continuing in this way, sixteen rings had been installed by the end of June, 1904, reaching to a depth of 120.75 m. (396 ft.). During this work cement was injected behind the injured rings of the outer lining, at depths of 102 and 106 m. (334 and 347 ft.). The flow of water varied between 12.25 and 17.25 l. (3.2 and 4.5 galls.) per minute, but increased after the last grouting at 106 m. (348 ft.) to 21.46 l. (5.7 galls.) per minute, so that satisfactory results from the grouting can scarcely be claimed. Towards the latter part of June, at 120.75 m. (396 ft.), the flow amounted to 76 l. (20 galls.) per minute, and at the same time a gradual rising of the shaft bottom became noticeable. At 121 m. (397 ft.) more cement grouting was forced behind the walls, and the shaft then allowed to fill with water, as a break in the bottom was feared which would have been disastrous to the damaged portion of the lining.

The sand and clay were then removed by boring under water, to the depth of one meter below the shoe, and a concrete plug, which reached up to the 121-m. (397-ft.) mark, was put in. After this has hardened, and towards the end of 1904, it is proposed to sink through it by hand, supporting the shaft

walls by suspended tubbing. A successful termination of this work is anticipated, because, where carried on in the damaged part of the lining, it will be protected by the concrete plug below. It is expected, moreover, that below the drop-shaft the sinking can be continued through the clay by hand-work.

5. The New Shaft of the "Thiederhall" Potash-mine, at Thiede, near Brunswick.

The first shaft of this company was put down under great difficulties, mainly because of the thick beds of overlying sand and loose water-bearing soils. It was started by the Haase process of sinking, which consists in driving vertically a circular series of wrought-iron pipes, set side by side and supported by interlocking guides to prevent deviation. The pipes in this case were 140 mm. (5.47 ins.) inside diameter by 110 mm. (43 ins.) thick. The process proved unsuccessful. Some of the pipes diverged outwards, others inwards, into the area of the shaft. A drop-shaft was therefore started inside of the ring of pipes. It consisted of machined cast-iron tubbing, with a cast-iron shoe, whose cutting edge was formed by a steel ring applied to the outside of the shoe. This was the first trial of this construction, which was suggested by Haniel & Lueg.

The work of sinking this shaft was begun in the early eighties of the last century. At first it progressed satisfactorily by the use of hydraulic jacks operated by hand, automatic jacks for this service being yet unknown. But difficulties soon arose, as the shoe encountered the Haase pipes and was obstructed by them. Five of the pipes were cut through without damage to the shoe, but segments of some of the shaft-rings were crushed and fragments of them forced into the shaft.

After experiencing many difficulties, the Chaudron method of sinking was eventually adopted and the shaft completed, though with a net diameter of only 2.8 m. (9.2 ft.). It is worthy of note that this was the first instance where a moss-box connection was attempted and successfully carried out in a rock-salt deposit.

The conditions existing where the new shaft was begun were more favorable, although some 46 m. (151 ft.) of sand and unstable, water-bearing ground occurred in the upper part of the formation, as follows:

0– 1.0 m. (0– 3.3 ft.).....	surface soil and clay
1. 0– 6.0 m. (3.3– 19.7 ft.). ...	coarse gravel
6. 0–30.0 m. (19.7– 98 ft.).....	fine sand with boulders
30. 0–30.5 m. (98– 99 ft.).....	clay
30. 5–46.11 m. (99– 151 ft.).....	fine sand and boulders
46.11 m.(151 ft)	clay

Haniel & Lueg recommended starting with a masonry drop-shaft and continuing the work with an iron drop-shaft and hydraulic jacks.

The first sod was turned March 12, 1901, and by March 25th the ground-water was reached at 6 m. (19.7 ft.). This preliminary excavation was walled with masonry 11.5 m. (38 ft.) in the clear, both for safety and to serve as a guide for the masonry drop-shaft. The walling was finished April 6th, the timber head-frame a month later, and sinking was resumed on May 7th. The cast-iron shoe for the drop-shaft was first laid, upon which the wall was started three bricks thick. Lowering began May 25th, the material being excavated with a claw-dredge and hoisting-engine.

By June 25th a depth of 22½ m. (74 ft.) was reached without incident, and a 3.5-m. (11.5 ft.) concrete plug put in the bottom. This was allowed to harden from July 5th to August 11th

and the shaft was unwatered between the 12th and 14th. Everything being in good shape, the anchorage-bolts and pressure-ring for the hydraulic jacks (patent No. 91,572) were immediately installed. The cast-iron drop-shaft, 6.4 m. (21 ft.) clear diameter, was next begun, with a cast-steel shoe 70 mm. (2.75 ins.) thick, strengthened by a 30-mm. (1.2 in.) steel band. The walls of the shaft were 65 mm. (2.5 ins.) thick, each ring being composed of twelve segments.

By September 27th all was in readiness, the shoe resting on the concrete plug at a depth of 18.34 m. (60 ft.). While this work was under way, the engines, boilers, and shaft-boring plant were in process of erection and were completed October 29, 1901. Boring was started October 30th with a 4.2-m. (13.78-ft.) trepan, and the concrete plug was cut through by November 9th. The ring of concrete remaining under the shoe was readily broken out, and virgin ground below the concrete reached on November 21st. Sinking with a claw-dredge was resumed and progressed without difficulty. On January 8, 1902, the drop-shaft encountered clay at 46.11 m. (151 ft.) and stuck fast February 20, 1902, at 53 m. (174 ft.), the shoe being embedded some 7 m. (23 ft.) in the clay.

The work of the drop-shaft was thus practically finished, nothing remaining but unwatering and calking the joints. The final junction with the underlying strata will be made in the usual way with a masonry footing and closing-ring.

Between November 21, 1901, and January 8, 1902, in sinking through sand, 18 rings, or 27 m. (88 ft.) of lining were put in; and of these forty-five days, only twenty-five were expended on the actual shaft-sinking, the other twenty being occupied by miscellaneous work and repairs on the dredging apparatus, pressure-pumps, etc. The daily advance, while

work was actually in progress, amounted to 1.08 m. (3.54 ft.) per twenty-four hours, and including all delays to 0.60 m. (1.97 ft.) per twenty-four hours.

6. Sinking of Shafts Nos. 4 and 5 of the Rheinpreussen Colliery, at Homberg on the Rhine.

The operations at all of the Rheinpreussen shafts have been important factors in the development of the various methods of sinking. This company was the first to attempt sinking through the heavy quicksands on the left side of the Rhine, the earlier ventures dating back to 1857. Shafts Nos. 1 and 2 were put down by the then superintendent Hochstrate, under difficulties calling for the highest efficiency, energy, and ingenuity of all concerned. Suitable methods and appliances, as well as previous experience in such work, were all lacking. For this reason it took twenty years to complete Shaft No. 1 and thirteen years for No 2. Vols. XI, XVII, XX, XXIII, and XXVII of the "Zeitschrift für das Berg-, Hütten- und Salinenwesen im Preussischen Staate" contain the details of these operations.

The history of Shaft No. 3, sunk by Manager Pattberg between 1892 and 1895, shows plainly the advance in methods and equipment since the first shafts were completed. It took somewhat more than three years to get through the quicksands. The hydraulic-jack plant (patent No. 91,572) was first used for this shaft, and the excavated material raised by means of sack-borers and claw-dredges. This work was described by Bergrath Lücke, of Aix-la-Chapelle, in Vol. XLIX of the "Zeitschrift für das Berg-, Hutten- und Salinenwesen im Preussischen Staate". It clearly demonstrated the superiority of

accurately machined cast-iron tubbing-rings over the rough ones or the plate-metal linings used in Shafts Nos. 1 and 2. At the close of his article the author dwells particularly on this point.

In sinking Shafts Nos. 4 and 5, all of the data and results secured at Shaft No. 3, as well as information from other sources, were carefully weighed and considered, especially as the diluvial and Tertiary formations were to be expected between the surface and the solid Carboniferous strata, which were some 160 m. (525 ft.) in depth.

The dimensions and equipment of both shafts were identical, in order to have all parts interchangeable. Both were started with masonry drop-shafts, 8.9 m. (29 ft.) in the clear, and continued to depths of 17 and 20 m. (56 and 66 ft.) by that means. Then concrete plugs were put in preparatory to installing the anchor-ring and bolts for the hydraulic-jack apparatus, which was designed for exerting a pressure of 3000 tons. Meantime the shafts were narrowed down by the masonry linings to an inside diameter of 7.85 m. (25.75 ft.). Next was begun the construction of composite drop-shafts, which measured 7.8 m. (25.6 ft.) outside and 6.5 m. (21.3 ft.) inside diameter, clear of the reinforcing-rings. These were sunk to a depth of 60.5 m. (198 ft.) in Shaft No. 4 and 74.5 m. (244 ft.) in Shaft No. 5.

Pattberg's drop-drill, or trepan, which has already been described, was used to much advantage in sinking these shafts. The concrete plug in the bottom of Shaft No. 4 was pierced in six days, or 0.5 m. (1.64 ft.) per twenty-four hours. The distance from the top of the concrete to a depth of 60.5 m. (198 ft.) was accomplished in thirty-four days' time, an average advance of 1.38 m. (4.5 ft.) per day. The experience thus gained was

immediately applied in Shaft No. 5, which meantime had been left standing. Speed here was increased, the progress in concrete being 0.81 m. (2.66 ft.) and in virgin ground 1.52 m. (5 ft.) per day.

The important features of the new method of boring were: the short drop of 200–300 mm. (78.–11.75 ins.), the high speed of 60 strokes per minute, and the use of water-jets to clear away the drillings. These were raised by compressed-air pumps, with very satisfactory results. Fig. 18 illustrates the trepan used, which was built by Haniel & Lueg according to designs of Pattberg. At times the work of installing the tubbing and masonry could not keep pace with the drilling, which had therefore to be delayed in order to allow the other work to catch up. Advances of 5 m. (16.4 ft.) per twenty-four hours were sometimes made in these shafts of 7.8 m. (25.6 ft.) diameter.

The hope that the use of the drop-drill would prevent deviations from the vertical was fully realized. Both of these shafts were absolutely vertical, and the lining perfectly free from cracks or other damage. The new method of using combined masonry and iron linings has also been a complete success.

At the end of the first stage of the work of sinking both shafts were filled 20 m. (66 ft.) deep with gravel, with the idea of obviating the use of a concrete plug, while still being able to remove the water preparatory to installing the iron drop-shafts. This resulted satisfactorily, as the lower strata traversed had proved to be rather more clayey than loose.

Unfortunately the thickness of only one compound drop-shaft was provided for in choosing the initial diameters, as the new method had never before been tested. For further advance two plain iron drop-shafts were projected. These were

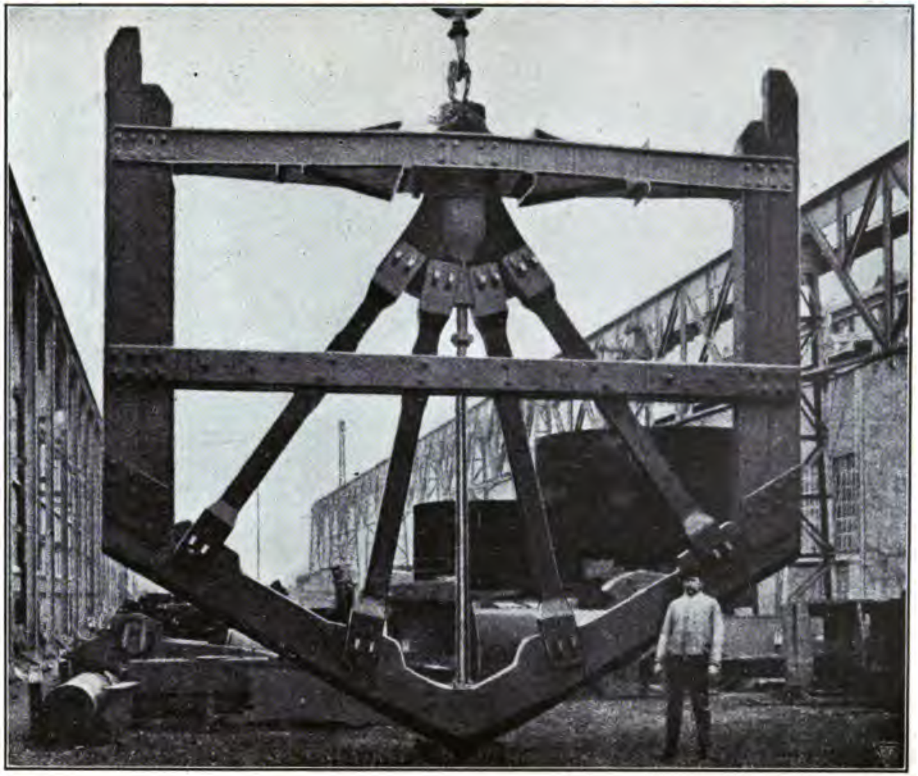

FIG. 18.—Shaft-trepan with Water-jet Apparatus. Designed by Pattberg.

therefore made 5.9 m. (18.35 ft.) inside diameter, with walls 90 mm. (3.5 ins.) in thickness and steel shoes with steel strengthening-bands and flanges for the future suspending of tubbing-rings. One of them, in Shaft No. 4, reached a depth of 93 m. (305 ft.), but could not be forced any deeper. As the shoe was well embedded in hard clay, the shaft was unwatered, in order to continue work in the bottom by hand. But the ground was still too soft to permit of sinking with suspended tubbing. Another short drop-shaft, 5.4 m. (17.7 ft.) diameter, was therefore lowered and a heavy staging constructed just above it in the 5.9 m. (18.35 ft.) lining, as a base for the hydraulic jacks. Sinking was continued by hand, so that on February 18, 1903, hard ground was finally reached at a total depth of 132 m (433 ft.), the entire work being brought to a successful completion in a little less than two years' time.

The water-tight connection at the bottom was effected by suspending from the drop-shaft shoe 13 tubbing-rings, each 500 mm. (1.64 ft.) high, which ultimately rested at 139 m. (456 ft.) on a wedging-crib. After the permanent lining had been completed, sinking was continued in the Carboniferous formation with a clear diameter of 5.5 m. (18 ft.), the masonry walling being 2½ bricks thick.

The procedure at Shaft No. 5 was similar to the above. In May, 1902, the 5.9 m. (18.35 ft.) drop-shaft shoe was placed in position at a depth of 43 m. (141 ft.) and the shaft-lining was built up to the surface and capped with the pressure-ring and hydraulic jacks. In September the work of forcing down the lining began, and in March, 1903, the shoe reached a depth of 96 m. (315 ft.). Here it stuck fast, as in the case of No. 4 Shaft, so that gravel was filled in to the 76 m. (249 ft.) level and the water removed.

At this point a new shoe was laid, upon which a drop-shaft 5.3 m. (17.4 ft.) inside and 5.66 m. (18.56 ft.) outside diameter was built up to the surface. Boring and sinking were resumed towards the end of August. At 104.5 m. (343 ft.) the drop-shaft stuck fast, after traversing a considerable depth of clay, and was then pumped out. As it was somewhat deformed in the lower part; it became advisable to reinforce it for a height of 10 m. (32.8 ft.) with masonry 2½ bricks thick, after which it was sunk to 118.9 m. (390 ft.).

A third iron drop-shaft, 4.7 m. (15.4 ft.) clear diameter, was installed in November, 1903, and reached the Carboniferous formation on April 1, 1904, at a depth of 155 m. (508 ft.), the excavation being carried on by hand. A permanent water-tight connection was then made in a manner similar to that which had been successfully used in Shaft No. 4.

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Plate II

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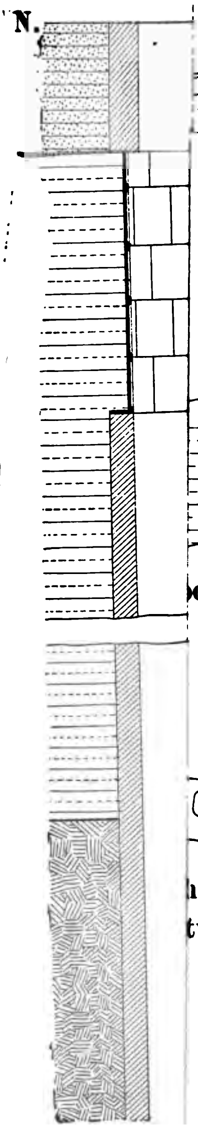

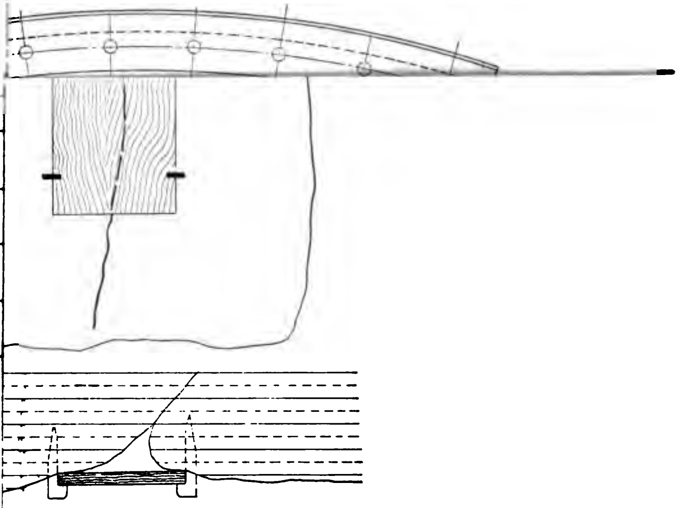

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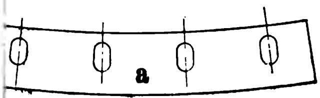

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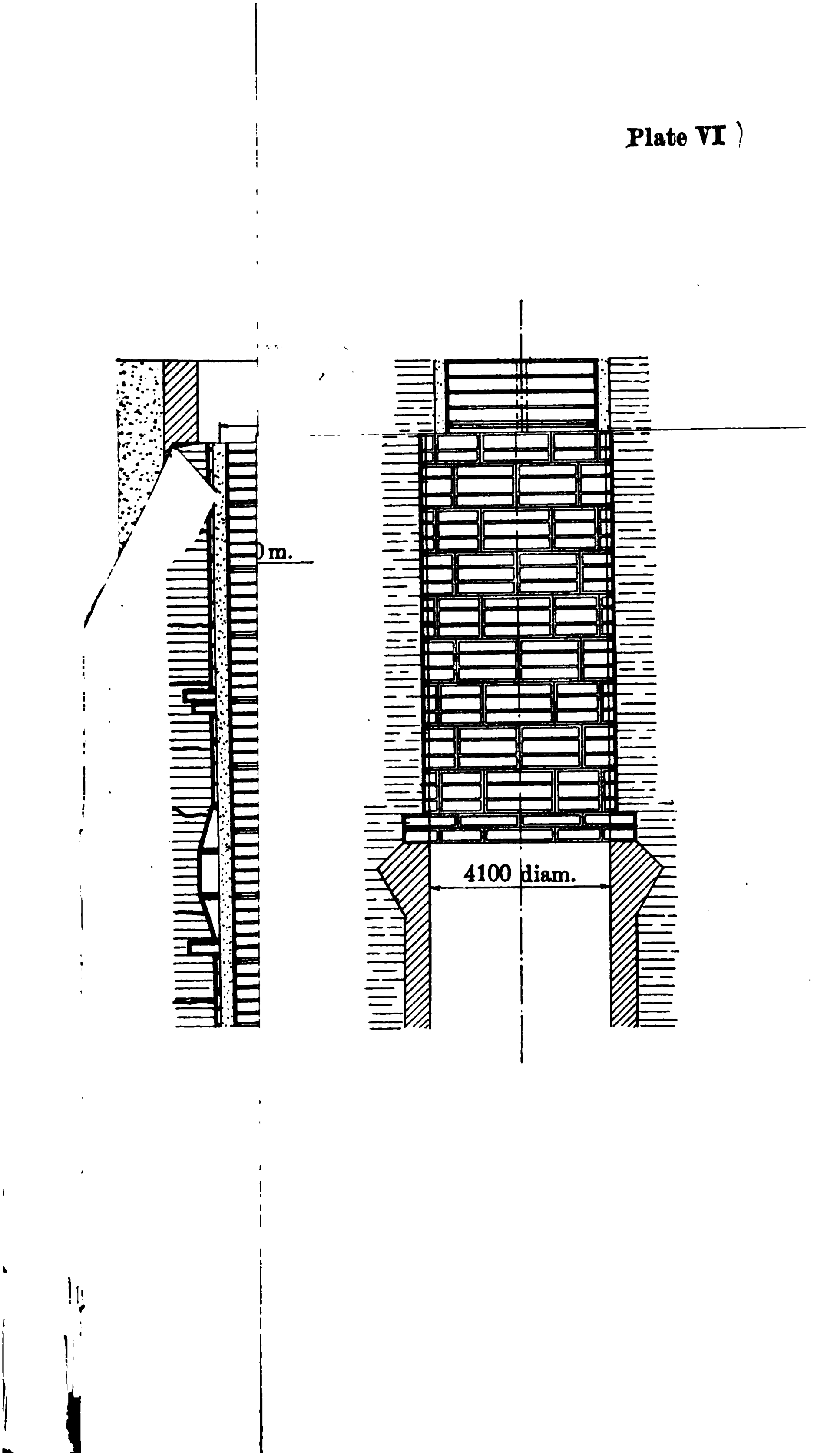
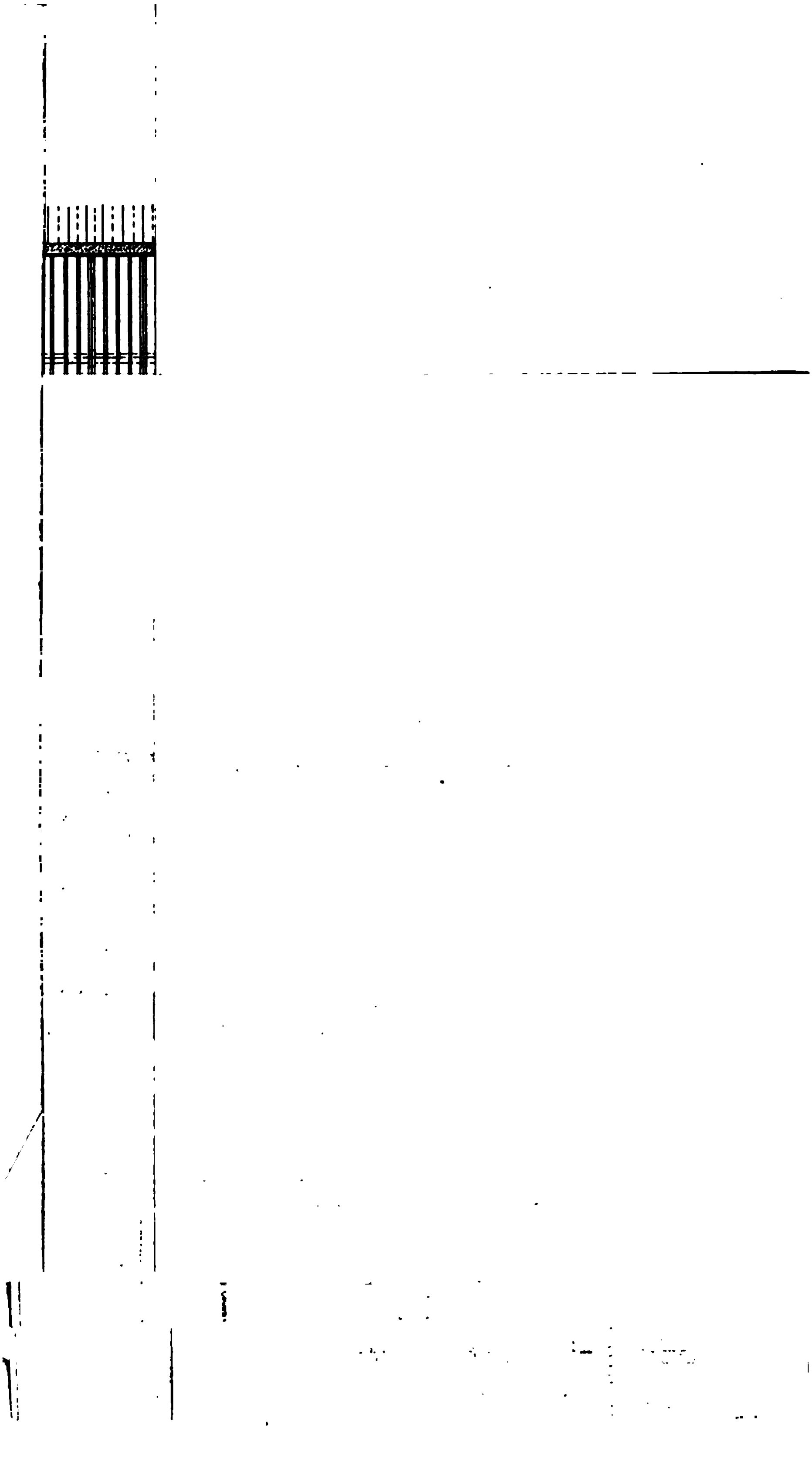
Plate VI





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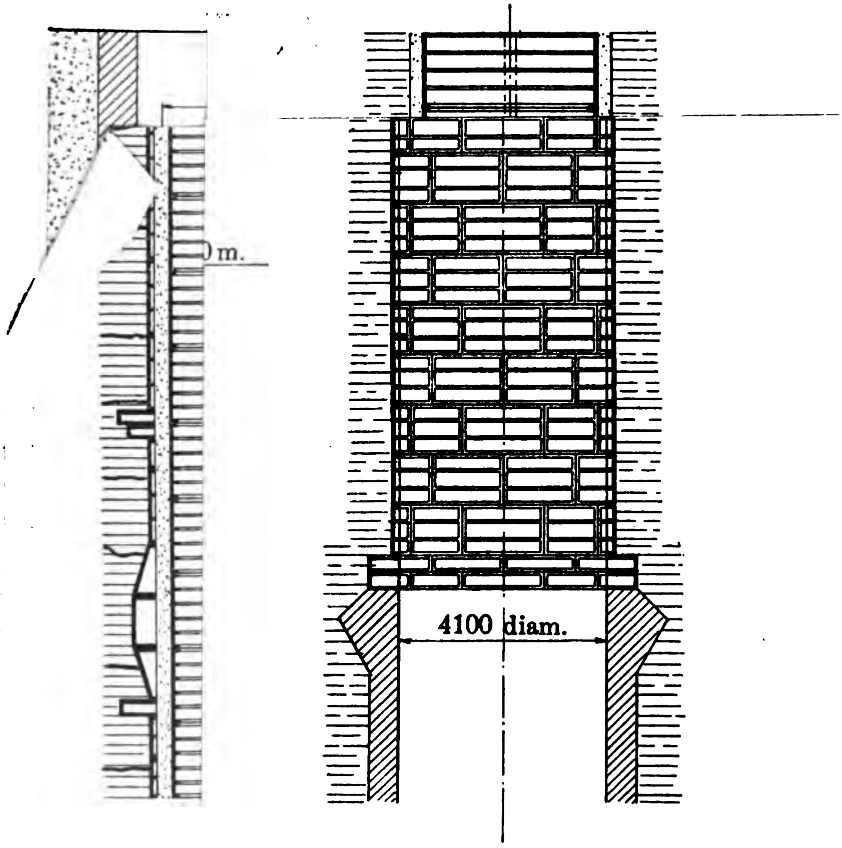

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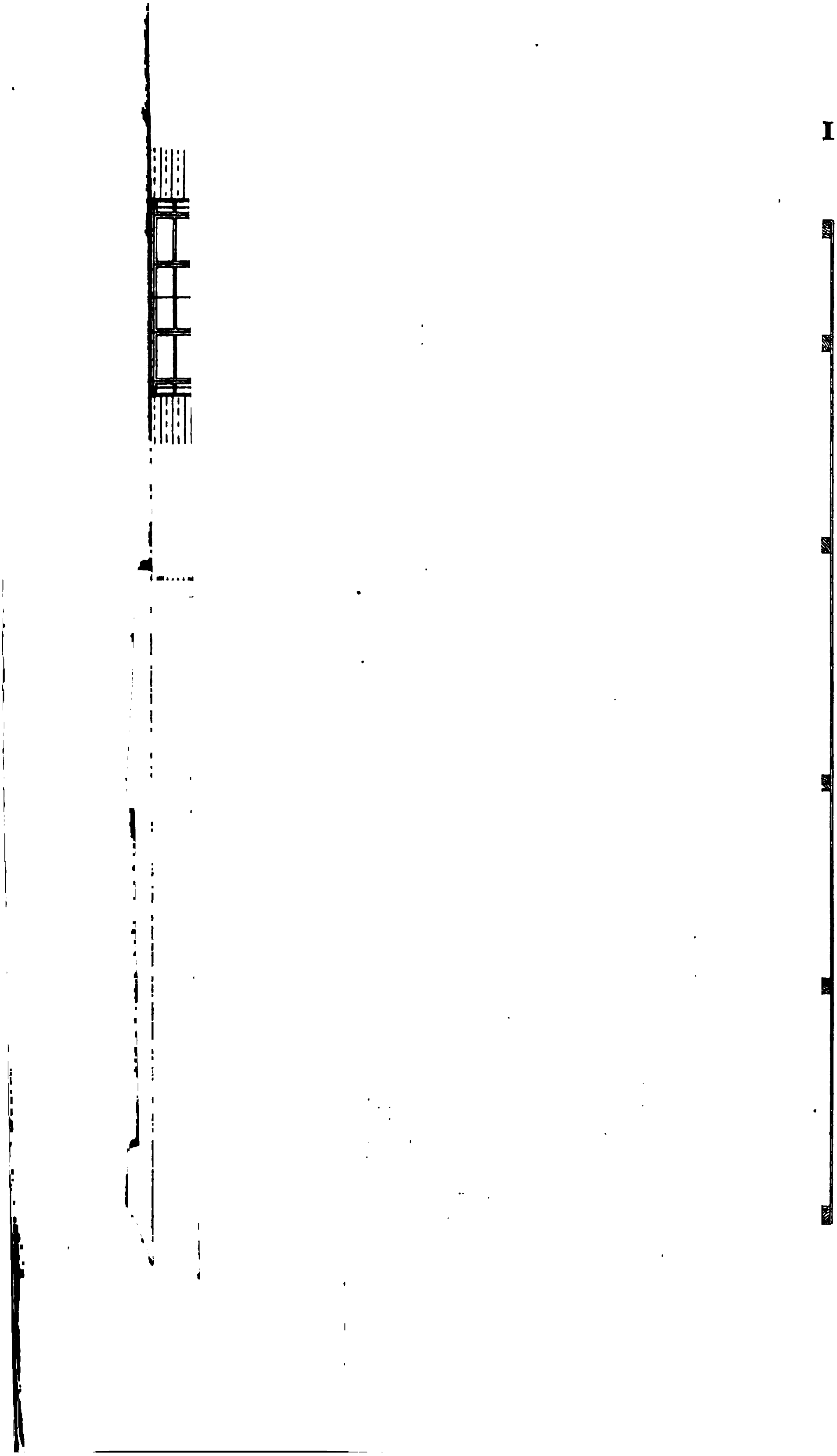

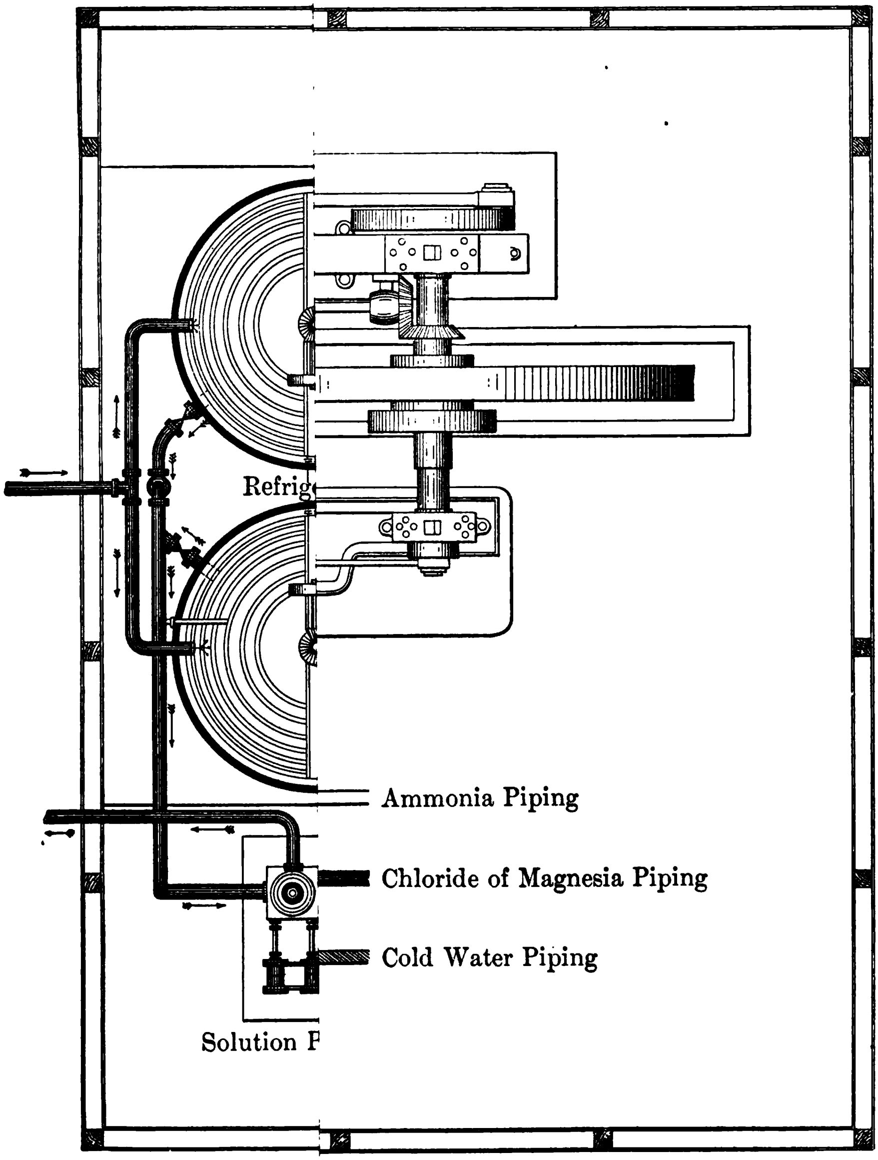
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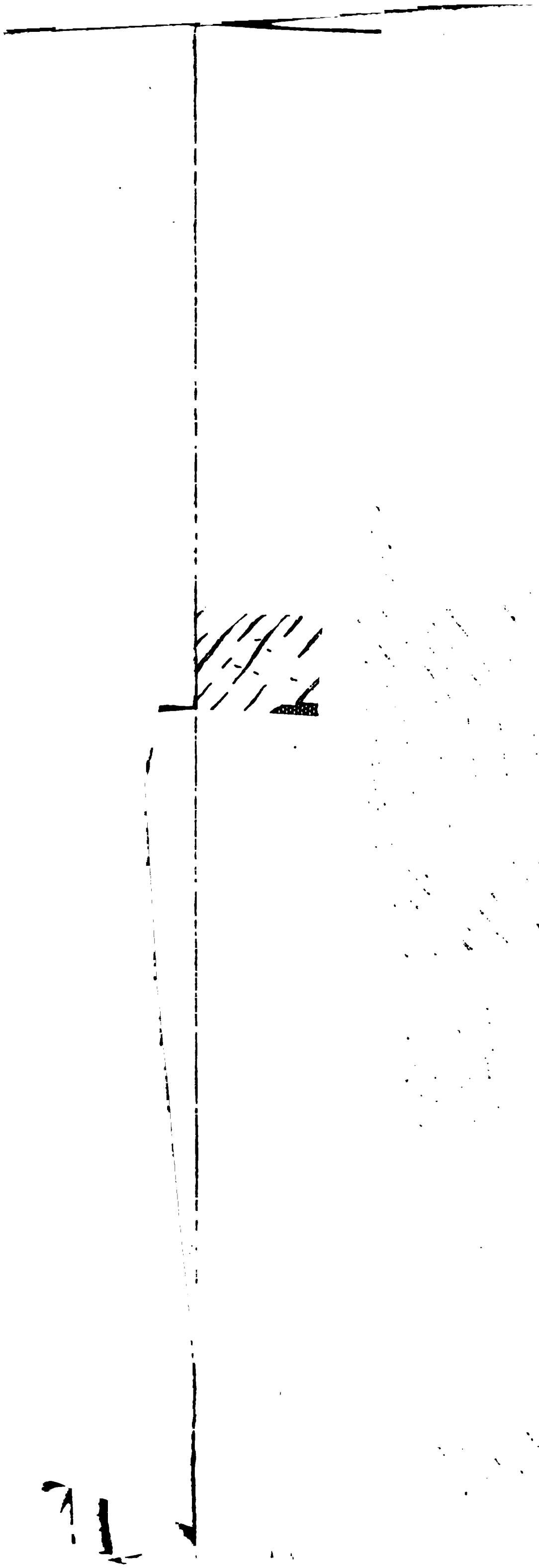
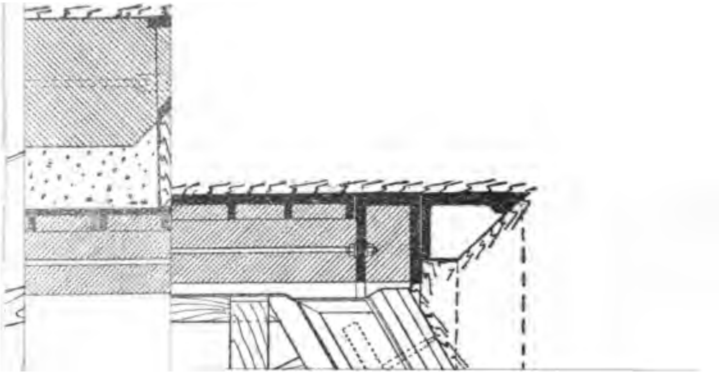


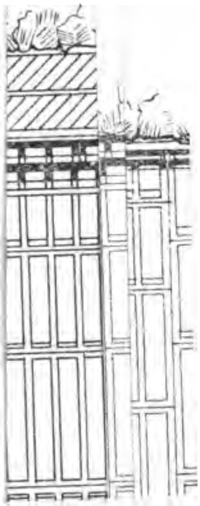


Percussion Boring Engine

Percussion Boring Engine

COMPANY

Plate XVIII



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